



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

### **LONG-RANGE OPERATIONAL MILITARY FORECASTS FOR AFGHANISTAN**

by

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March 2007

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<b>REPORT DOCUMENTATION PAGE</b>			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
<b>1. AGENCY USE ONLY (Leave blank)</b>		<b>2. REPORT DATE</b> March 2007	<b>3. REPORT TYPE AND DATES COVERED</b> Master's Thesis	
<b>4. TITLE AND SUBTITLE</b> Long-Range Operational Military Forecasts for Afghanistan			<b>5. FUNDING NUMBERS</b>	
<b>6. AUTHOR(S)</b> Sarah M. Moss			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> Naval Postgraduate School Monterey, CA 93943-5000			<b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b>	
<b>9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> N/A				
<b>11. SUPPLEMENTARY NOTES</b> The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
<b>12a. DISTRIBUTION / AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited			<b>12b. DISTRIBUTION CODE</b> A	
<b>13. ABSTRACT (maximum 200 words)</b>  We have investigated statistically significant signals in Afghanistan associated with two global scale climate variations, El Niño-La Niña (ENLN) and the North Atlantic Oscillation (NAO). The results of primary interest were in seasonal 850hPa temperatures and precipitation rates (PR), as these variables affect many military operations. Our primary data sets were National Centers for Environmental Prediction (NCEP) reanalysis fields and indices of ENLN and NAO activity. Our methods involved a two-step process. We first performed composite analyses of past events in an effort to identify statistically significant (SS) relationships between climate variations and 850hPa temperatures and PRs for Afghanistan. If SS was identified, we then used a forecast of ENLN or NAO conditions to produce a probabilistic forecast of potential occurrence of the particular variable, with a two-week lead time. We identified statistically significant results in all four seasons for both ENLN and NAO. The NAO has a larger impact on 850hPa temperatures while ENLN has a larger impact on PRs. The ENLN impacts on PRs are associated with anomalous advection of moisture out of the Arabian Sea or out of central Asia. The NAO impacts on 850hPa temperatures are associated with variations in storm tracks over southwest Asia. We generated initial probabilistic forecasts of PRs and 850hPa temperatures for Afghanistan for all four seasons. These serve as first steps in providing in-depth climatological planning products to military commanders and bridging the gap between civilian and military climatological products.				
<b>14. SUBJECT TERMS</b> Afghanistan, El Niño, La Niña, North Atlantic Oscillation, Long Term Mean, Climatology, Climate Variation, Climate Anomaly, Precipitation Rate, Moisture Transport, Smart Climatology, Climatological Support, Military Operation, Military Planning, Statistical Significance, Composite Analysis, Seasonal Forecast			<b>15. NUMBER OF PAGES</b> 99	
			<b>16. PRICE CODE</b>	
<b>17. SECURITY CLASSIFICATION OF REPORT</b> Unclassified	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> Unclassified	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> Unclassified	<b>20. LIMITATION OF ABSTRACT</b> UL	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)  
Prescribed by ANSI Std. Z39-18

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**LONG-RANGE OPERATIONAL MILITARY FORECASTS FOR AFGHANISTAN**

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Submitted in partial fulfillment of the  
requirements for the degree of

**MASTER OF SCIENCE IN METEOROLOGY**

from the

**NAVAL POSTGRADUATE SCHOOL  
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## **ABSTRACT**

We have investigated statistically significant signals in Afghanistan associated with two global scale climate variations, El Niño-La Niña (ENLN) and the North Atlantic Oscillation (NAO). The results of primary interest were in seasonal 850hPa temperatures and precipitation rates (PR), as these variables affect many military operations. Our primary data sets were National Centers for Environmental Prediction (NCEP) reanalysis fields and indices of ENLN and NAO activity.

Our methods involved a two-step process. We first performed composite analyses of past events in an effort to identify statistically significant (SS) relationships between climate variations and 850hPa temperatures and PRs for Afghanistan. If SS was identified, we then used a forecast of ENLN or NAO conditions to produce a probabilistic forecast of potential occurrence of the particular variable, with a two-week lead time.

We identified statistically significant results in all four seasons for both ENLN and NAO. The NAO has a larger impact on 850hPa temperatures while ENLN has a larger impact on PRs. The ENLN impacts on PRs are associated with anomalous advection of moisture out of the Arabian Sea or out of central Asia. The NAO impacts on 850hPa temperatures are associated with variations in storm tracks over southwest Asia.

We generated initial probabilistic forecasts of PRs and 850hPa temperatures for Afghanistan for all four seasons. These serve as first steps in providing in-depth climatological planning products to military commanders and bridging the gap between civilian and military climatological products.

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## LIST OF ACRONYMS AND ABBREVIATIONS

ACMES	Advanced Climate Modeling and Simulations
AFCCC	Air Force Combat Climatology Center
AFWA	Air Force Weather Agency
AH	Arabian High
AMJ	April-May-June
AN	Above Normal
AO	Arctic Oscillation
BN	Below Normal
CPC	Climate Prediction Center
CAF	Composite Analysis Forecast
DoD	Department of Defense
ECMWF	European Centre for Medium Range Weather Forecasts
EN	El Niño
ENLN	El Niño/La Niña
ENLN	El Niño-Southern Oscillation
ESRL	Earth Systems Research Laboratory
ETC	Extra-tropical cyclone
FOA	Forward Operating Agency
IRI	International Research Institute for Climate and Society
IO	Indian Ocean
JAS	July-August-September
JFM	January-February-March
JMA	Japanese Meteorological Association
LN	La Niña
LTM	Long-Term Mean
MC	Maritime Continent
MEI	Multivariate ENLN Index
MRF	Medium Range Forecast
NAM	Northern Hemisphere Annular Mode
NAO	North Atlantic Oscillation

NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NN	Near-Normal
NOAA	National Oceanic and Atmospheric Administration
OLR	Outgoing Longwave Radiation
OND	October-November-December
PR	Precipitation Rate
RCPA	Rotated Principal Component Analysis
SLP	Sea Level Pressure
SS	Statistical Significance
SST	Sea Surface Temperature(s)
STJ	Sub-Tropical Jet
SWA	Southwest Asia
SWPG	Seasonal Working Prediction Group
TCC	Tokyo Climate Center
TOF	Tendency Oscillation Forecast
UKMO	UK Meteorological Office

## ACKNOWLEDGMENTS

I would like to thank the many NPS Department of Meteorology faculty whose instruction guided me down this path. Specifically, I would like to thank Mary Jordan and Professor Harr for their never-ending time and wisdom.

I would like to extend a special thank you to Dr. Warren Blier at NWS-Monterey office for taking time to discuss the best direction for my research.

Also, I would like to extend a special thank you to Marina Timofeyeva, with NOAA, for being such an instrumental part of figuring out this puzzle. Always available to answer my many questions, I would not have gotten this far in the process without her expertise.

My partner in crime, Chris Hanson, deserves many things, and in this capacity, a very large piece of gratitude. We experienced this process together, and I hope we have delivered a good piece of work to the weather community; without your guidance and inputs, it would simply be a piece of work.

I would like to thank the trials and tribulations of the modern and advanced climatology course students. Without our collective brain power, many of the conclusions presented in this study would still be on the drawing table.

I extend the most special of thank you to my thesis advisors, Tom Murphree and Lt Col Karl Pfeiffer. We all know that I would not be here without your wisdom, patience, and guidance; but what we all do not know is that I am very grateful to have received such guidance from two of the most intelligent people I know.

Lastly, but certainly never least, I would like to thank my husband, Carl. His support was unfaltering, and I would not have survived this process without his hands to fall back on.

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# **I. INTRODUCTION**

## **A. BACKGROUND**

Throughout history, accurate climate and weather information has been vital to military operations. The harsh winter of 1777 depleted the Continental Army based at Valley Forge during the Revolutionary War (Cantrell 2004). Storms off the coast of the Hawaiian Islands concealed Japanese aircraft carriers and pilots as they initiated their attack on Pearl Harbor (Goddard Space Flight Center 2001). D-Day in June 1944 was executed during a perfect window of opportunity as favorable weather conditions were accurately forecast for the U.S. and its allies (Cantrell 2004). Most recently, clear skies provided prime conditions for the terrorist attacks on the World Trade Center and the Pentagon (Cantrell 2004). These scenarios are only a small sample, but illustrate how climate and weather information can prove advantageous for either side in a conflict. The key is to know in advance how to take advantage of climate and weather conditions, and planning for both favorable and adverse conditions.

Advances in technology and in the field of meteorology over the past six decades have led to an increased interest in weather information and its applications (Chagnon 2004). Around 1970, satellite technology was integrated into weather applications. Variables not observed by prior methods could now be measured and recorded. One example is outgoing longwave radiation (OLR), in which cloud-top temperatures are inferred from satellite observations of outward directed longwave radiation leaving the atmosphere. OLR measurements are used to estimate areas of convection. This information greatly improved the monitoring of highly convective regions, such as the western tropical Pacific Ocean, and helped to identify long term fluctuations in convection associated with climate oscillations such as El Niño-La Niña (ENLN). The use of satellite information also greatly aided the identification of links between major global climate anomalies occurring around the globe (e.g., major floods, droughts, and extreme temperatures). These relationships helped to redirect the focus of the climate community from an emphasis on long term means (LTMs), to deviations

from the LTMs, or *climate anomalies*, and their impacts on the physical environment and socioeconomic conditions (Chagnon 2004). Advances in climate science data and methods, and an increasing emphasis on climate variations, are key aspects of modern climatology.

The application of modern climatology methods has not been universal - these advanced techniques are not consistently applied across both the civilian and military sectors. While the civilian sector has led the way with adaptation of modern climatology into climate analysis and forecasting, the military sector continues to rely on traditional climatological data sets and methods, and pays very little attention to climate variations. Thus, military climate products are based almost exclusively on LTMs (Murphree 2006c). The traditional climatology practiced by the military does not, and cannot, adequately account for extremes that can significantly alter the global climate system, and so it also cannot account for significant anomalies and their impacts on operations within a region of military importance. Traditional climatology products are thus limited in their influence on operations (e.g., logistics, weapons selection, and other aspects of mission planning). Applying modern climatology techniques provides a more representative depiction of the climate system of a region and also allows for greater anticipation of, and planning for, possible anomalous conditions. Timely and accurate environmental information increases the likelihood of minimizing the impact of adverse conditions on military operations, and, therefore, can directly improve the planning and execution of those operations (Murphree 2006c, AFCCC 2003).

There are many well-known and monitored global scale climate variations. Two examples that are important in many politically significant regions are ENLN and the North-Atlantic Oscillation (NAO). These variations and their global impacts have been examined in many studies. In particular, the studies by Vorhees (2006) and LaJoie (2006) document that ENLN and the NAO have major impacts on weather and climate in regions of great importance to Department of Defense (DoD) planning and operations. Thus, these studies provide a very convincing argument for why the DoD should consider revising its



current approach to providing climatological support for military operations. For example, instead of creating and distributing products based almost entirely on LTMs, the DoD should also issue products that account for large-scale climate variations (e.g., ENLN, NAO). To do so, the DoD needs to adopt modern climatology, also known as smart climatology, techniques.

A LTM is an average of a range of values from many consecutive years (e.g., 30 years) for a given weather variable (AFCCC 2003). A LTM gives only a blurred depiction of extremes or deviations from the mean, and so cannot provide planners complete information on the possible or probable conditions for a region. LTMs can be used to provide some information about extreme conditions (e.g., average daily maxima, standard deviations, etc.), but an exclusive reliance on LTMs precludes the development of state of the art climate analyses and forecasts (e.g., analyses of the conditional probability of extreme precipitation given the occurrence of a given state of the global scale system, such as an El Niño or La Niña state). Modern climatology investigates the processes responsible for driving global and regional deviations, and provides analyses and forecasts that directly account for climate variations (Murphree 2006c). As an example, knowing weeks to months ahead of time that a given oscillation is in a particular phase (e.g., the EN phase of ENLN), forecasters can use modern climatology techniques to identify the associated dynamics over their region and forecast the probability of extreme conditions associated with the phase, such as anomalously high precipitation in southeastern Afghanistan. This type of information could be presented in an extended-range (e.g., two weeks to six months) outlook, allowing commanders to better plan military operations. Should the DoD continue to use traditional climatology to develop its weather and climate products, there is a definite likelihood that past environmentally-related problems during the planning and execution of military operations will be repeated.

The Persian Gulf War during the early 1990s is a perfect recent example of how US military operations have been negatively impacted by weather. Barry

D. Watts, in *Clausewitzian Friction and Future War* (Watts 2004), discusses how the unanticipated adverse weather became a lesson-learned for US forces:

Adverse weather conditions substantially disrupted operations, especially during the early days of the air campaign and the Coalition's ground offensive at the conflict's end. On the second and third nights of the war, more than half of the planned F-117 strikes were aborted or unsuccessful due to low clouds over Baghdad; on the second day of the ground campaign (25 February 1991), all F-117 sorties were canceled due to weather. So disruptive did the cumulative effects of adverse weather become on the air campaign that the Coalition's head air planner, (then) Brigadier General Buster C. Glosson, came to view it as his "number-one problem" and, by implication, as a greater impediment than the Iraqi Air Force.

Sixteen years later in Operations ENDURING FREEDOM and IRAQI FREEDOM in Southwest Asia (SWA), there have been many prolonged periods of adverse weather since the operations began. Despite the lessons learned in the Persian Gulf War, DoD meteorologists have had great difficulty in analyzing and forecasting extended periods of anomalous weather, and thus have been unable to provide accurate long-lead forecasts to commanders (Vorhees 2006). In a specific example, forecasters did not foresee the onset of extreme winter precipitation for Afghanistan and Pakistan during the 2004-2005 winter season, which directly followed a devastating earthquake that displaced thousands of residents. Had DoD forecasters had access to modern climatology data and products, they would have been able to provide state of the art, long-range weather outlooks that highlighted the potential for anomalous precipitation conditions, allowing planners to better prepare for adverse conditions (Vorhees 2006). Instead, military and humanitarian operations were severely hampered by unforeseen extreme snowfall and the resulting spring floods (Vorhees 2006, Murphree personal communication 2006).

In a recent article by the Associated Press, the immediate need for modern climatology products by military leadership was highlighted by US Army Brigadier General Douglas Pritt, who oversaw the training of Afghan fighters in late 2006. General Pritt stated that he was hoping for heavy snowfall over the

country so that his soldiers, who are trained to handle such conditions, can take advantage of the season that Taliban fighters typically use as a break in fighting: “If the Taliban is trying to rearm, refit and wait out the winter, then we’ll know they’re there” (Associated Press 2006). This is a perfect example of how of a long-range seasonal outlook could be directly applied to military and operational planning. In order for forecasters to be able to develop and provide this kind of product, DoD weather organizations must employ modern climatological analysis and forecasting techniques, and specifically, must consider the regional impacts of large-scale climate variations, such as ENLN and NAO (LaJoie 2006, Vorhees 2006). U.S. military operations in SWA are likely to continue for many years. Thus, it is in the best interests of the DoD to adopt and apply modern climatological techniques, focusing specifically on understanding the impacts of these large-scale climate variations on SWA. In this study, we have applied modern climatology, or smart climatology, techniques to examine the feasibility of generating DoD long-range seasonal forecasting products for Afghanistan.

## **B. AFGHANISTAN CLIMATE SYSTEM**

### **1. Geography**

To understand the climate system of Afghanistan and SWA in general, we will first discuss the geography. For this study, SWA will be defined as the region of Asia and northeast Africa within 30°-80°E and 10°-45°N (Fig. 1). The complex terrain across SWA has major influences on the climate system. The Zagros and Alborz Mountains in Iran and the Hindu Kush Mountains in Afghanistan, for example, exert a major influence on the regional precipitation distribution (Vorhees 2006). Precipitation is observed primarily during the winter and early spring months with eastward-moving extratropical synoptic storms, such as the Cyprus and Genoa low pressure systems out of the Mediterranean Sea, the Black Sea and Caspian Sea low pressure systems from the same-name bodies of water to the north, and the Atlas low pressure systems that form in the Atlas Mountains in Northeastern Africa (Barlow et al. 2005). It is not unusual for these storms to cause strong winds and blinding dust storms, with large amounts of local precipitation. Snow is common in the higher elevations, such as the Hindu

Kush Mountains throughout the central and northeastern portions of Afghanistan (AFCCC 2004; Vorhees 2006).

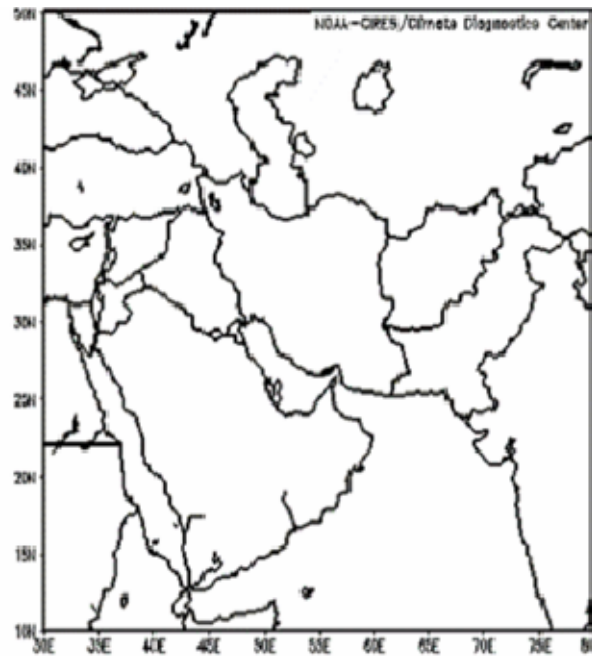


Figure 1. Map of Southwest Asia. From <http://www.cdc.noaa.gov/> (Accessed 20 March 2007).

Afghanistan occupies 650,000 sq km (roughly the size of the U.S. state of Texas), and is bordered by China, Iran, Pakistan, Tajikistan, Turkmenistan, and Uzbekistan (CIA 2006, Fig. 2). Afghanistan's elevation varies significantly within its borders, from only hundreds of meters in the Margow Desert and Amu Daya Valley lowlands in the southern and northern sections of the country, respectively, to greater than 4500m in the Hindu Kush Mountains in the middle of the country (AFCCC 2004, Fig. 3).

The Arabian Sea, Indian Ocean (IO), Persian Gulf, Gulf of Oman, and the Caspian Sea all serve as influential bodies of water and moisture sources for synoptic-scale low pressure systems that affect Afghanistan (Vorhees 2006; CIA 2006). The Caspian Sea is the region of cyclogenesis for the Caspian Sea Low pressure systems that transit Afghanistan during the fall and winter seasons (AFCCC 2004). These systems are responsible for a majority of Afghanistan's precipitation (Vorhees 2006).

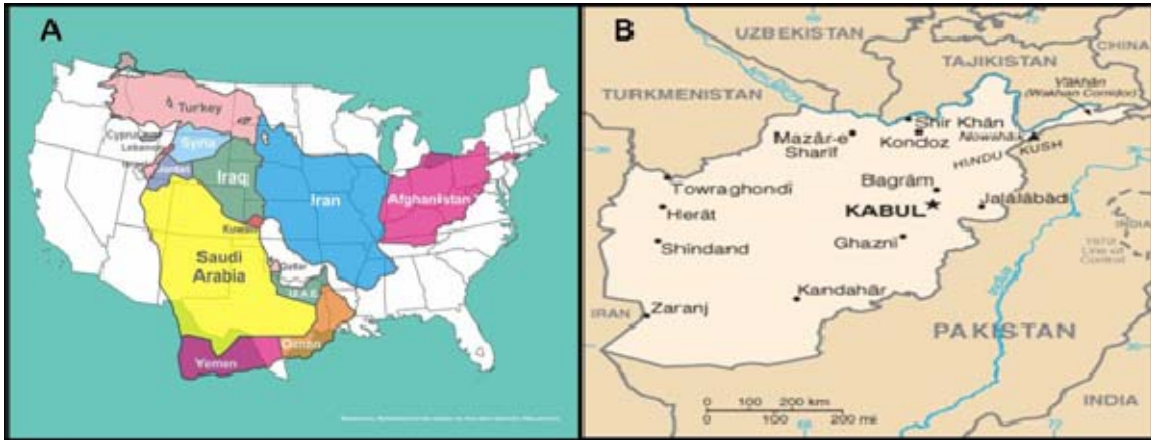


Figure 2. (a) Relative size of SWA as compared to the U.S. From AFCCC (2004). (b) Afghanistan and bordering countries. From CIA (2006).

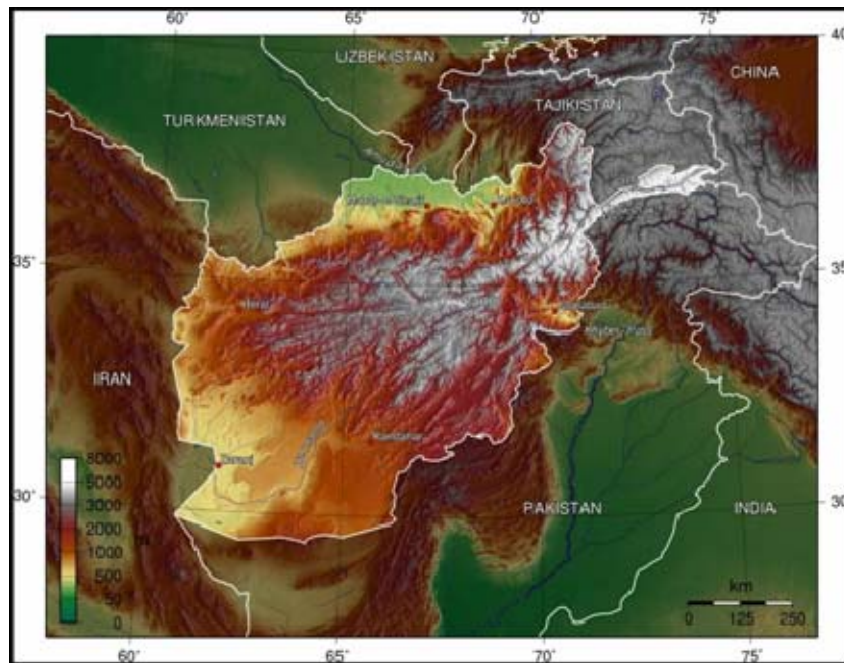


Figure 3. Physical relief map of Afghanistan highlighting the extreme elevation changes across the country. The Hindu Kush Mountains bisect the country. Figure courtesy of <http://gmt.soest.hawaii.edu> (Accessed 19 February 2007).

## 2. LTM Climate of Afghanistan by Season

According to the Afghanistan Climate Overview compiled by the Air Force Combat Climatology Center (AFCCC), the region's overall climate is dry, dusty, and relatively cloud-free (AFCCC 2004). The average conditions suggest an arid desert/semiarid steppe climate; however, closer inspection shows that the

climate of Afghanistan is highly varied due the interaction of several factors: the large-scale low pressure systems that frequent the region, the broad coverage of the Hindu Kush Mountains that bisect the country, and drought conditions that are common to the area (AFCCC 2004). These factors lead to large variations in temperature, precipitation, and cloud cover. For more detailed information on regional Afghanistan climate, the reader is referred to the publications by AFCCC and their documented sources.

**a. *Winter (Jan-Mar)***

During winter, the climate is primarily driven by the Asiatic (or Siberian) High. This strong high pressure center is a low level semi-permanent feature spanning most of Asia (Fig. 4). Radiational cooling from the interior of Asia generates the intense cold air associated with the Asiatic High; this cold air penetrates much of Afghanistan until the high begins to dissipate in the spring. Continuous low level ridging over SWA is characteristic this time of year as the Asiatic High tends to merge with the Saudi Arabian High, the Saharan High, and the Azores High (AFCCC 2004). The high pressures to the west and south of Afghanistan can cause strong low level westerly winds out of the Mediterranean Sea, Arabian Sea, Persian Gulf, and Indian Ocean that advect moisture into the region. Winter is a primary precipitation season for Afghanistan (AFCCC 2004).

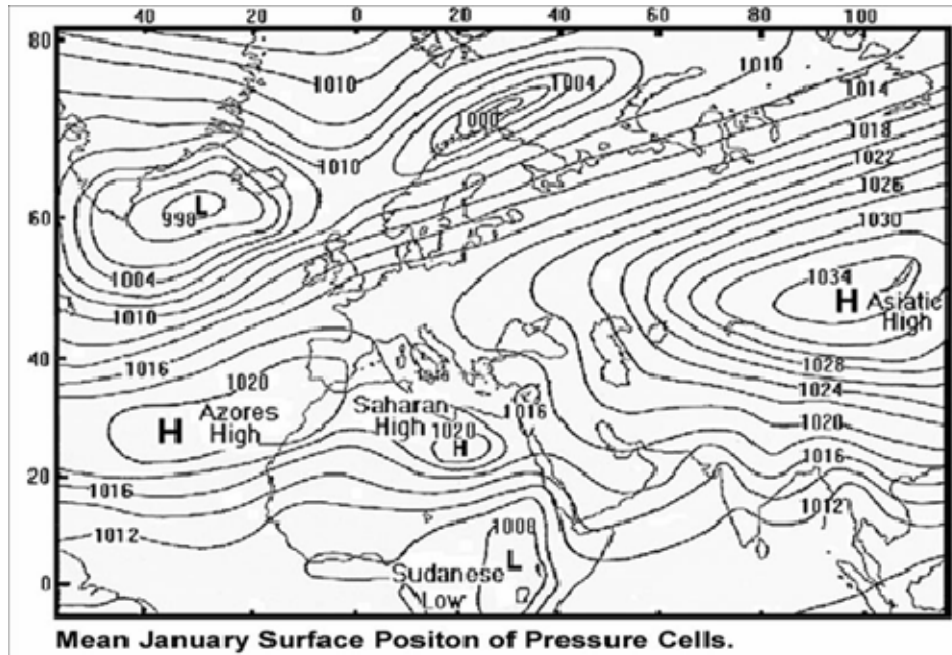


Figure 4. Mean January surface position of pressure cells over SWA. The Asiatic High is centered over Siberia, while other key winter surface pressure centers are located to the west and south of Afghanistan. From AFCCC (2004).

The primary low pressure systems for Afghanistan are the Cyprus, Caspian Sea, and Black Sea Low pressure systems (Figs. 5-6). The Cyprus and Caspian Sea Lows typically move eastward from the Mediterranean and Caspian Sea regions, retaining little of their original moisture as they encounter the Zagros Mountains in northern Iraq and western Iran. When these low pressure systems track into Afghanistan, the resulting precipitation is mostly in the form of snow in the upper elevations (AFCCC 2004, Vorhees 2006).

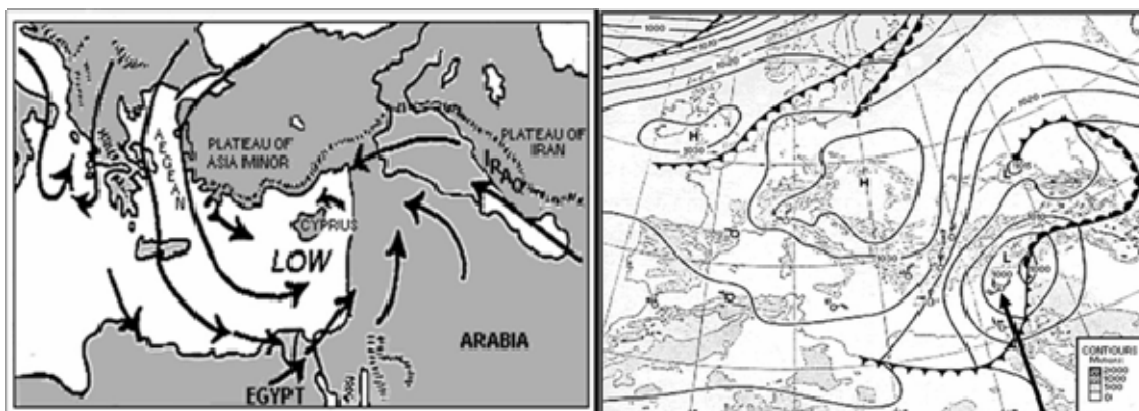


Figure 5. Cyprus Low frontogenesis region with typical pressure pattern associated with the feature. From AFCCC 2004.

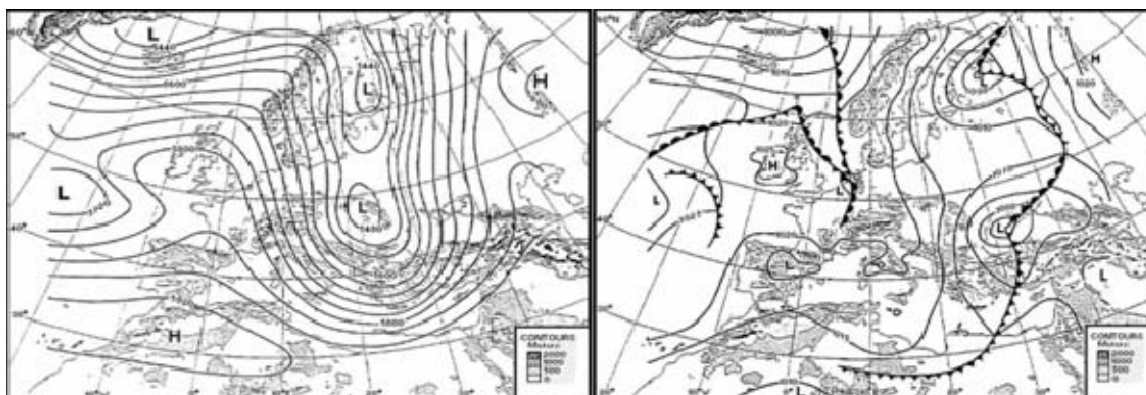


Figure 6. Black Sea Low frontogenesis region with typical pressure pattern associated with the feature. From AFCCC (2004).

### ***b. Spring (Apr-Jun)***

The spring season is a transitional period between the northeast monsoon and the southwest monsoon. As insolation increases, the Siberian High weakens and retreats northward and the Tibetan Plateau High. As the Asian landmass warms up, the subtropical jet (STJ) begins to shift north of the Himalayas and Afghanistan begins to warm up (AFCCC 2004). The number of synoptic storms begins to decrease towards the end of May into June. The shift of winds brings drier, dustier conditions over the majority of the country. Thermal troughing becomes evident across SWA, stretching from western North Africa into Southeast Asia; this is a defining feature of the summer season (AFCCC 2004).



**c. Summer (Jul-Sep)**

Once the Tibetan Plateau High and the thermal trough are established, they are easily detectable at 850hPa. Winds south of the trough tend to converge into the thermal trough and into the Pakistani Heat Low, a key feature of the thermal trough, resulting in large-scale southwesterly flow. The Tibetan Plateau anticyclone creates strong, large-scale subsidence that inhibits summer precipitation over Afghanistan. The monsoonal precipitation over India and Pakistan in this season is typically blocked by Afghanistan's mountainous terrain, although some convective activity does occur in the eastern part of the country (Vorhees 2006, AFCCC 2004).

North of the thermal trough, there are usually persistent northwesterly Shamal winds. These winds are generated by the gradient between the Pakistani Heat Low and the Tibetan Plateau High to the north. The strength of the monsoon and any passing extra-tropical weather systems to the north control these Shamal winds. These persistent northwesterly winds are responsible for dust advection in the western third of the country, and when strong enough, create blinding and persistent dust storms that span large areas and severely impact visibilities (AFCCC 2004).

**d. Autumn (Oct-Dec)**

Autumn is the season in which the warm and dry conditions of the southwest monsoon period end and the cooler and wetter conditions of the northeast monsoon period set in. As insolation decreases, the Pakistani Heat Low begins to diminish, completely disappearing by October (AFCCC 2004). The Asiatic High begins to develop. The low level winds over the Arabian Sea and the northwestern IO begin to reverse direction and become northeasterly and offshore (Vorhees 2006). The polar front jet and STJ begin to dip further southward with the decrease in temperatures, and the storm track shifts accordingly (Fig. 7). The first precipitation is typically observed in October, with precipitation events increasing in frequency as the season progresses.

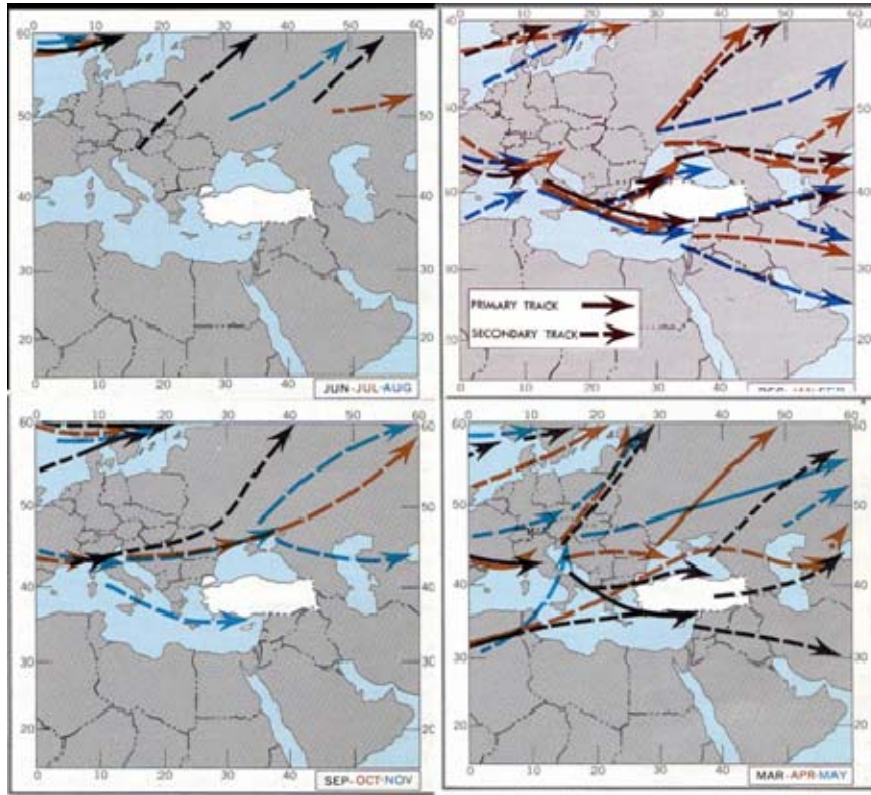


Figure 7. Climatological storm tracks for the four seasons. The top left shows typical storm tracks for Jun-Jul-Aug. The bottom left shows typical storm tracks for Sep-Oct-Nov. The top right shows typical storm tracks for Dec-Jan-Feb. The bottom right shows typical storm tracks for Mar-Apr-May. From AFCCC (2004).

### C. CLIMATE VARIATIONS AND THEIR IMPACTS ON THE REGION

Throughout the year, SWA can be affected by conditions in the Maritime Continent (MC) region, located in the tropical eastern Indian and western Pacific Oceans. Tropical convection in the MC is common throughout the year, especially in the northern autumn and winter. This convection generates a persistent tropical Rossby-Kelvin wave response (Matsuno 1966, Gill 1980, Fig. 8), which includes upper level ridging and low level troughing to the northwest and southwest of the convective region. This Rossby-Kelvin wave response often extends westward over the northwest IO and SWA and affects circulation and moisture advection of the SWA (Barlow et al. 2005, Vorhees 2006). Fluctuations in MC convection can lead to fluctuations in the impacts of the Rossby-Kelvin wave response on SWA (Vorhees 2006). Persistent fluctuations are linked to

global scale climate variations including ENLN, the Indian Ocean Zonal Mode (IOZM), and the Madden-Julian Oscillation (MJO) (Barlow et al. 2005, Vorhees 2006, LaJoie 2006, Stepanek 2006). For example, Barlow et al. (2005) and Mariotti et al. (2004) found that enhanced convection in the eastern IO and MC regions may lead to suppressed rainfall in SWA.

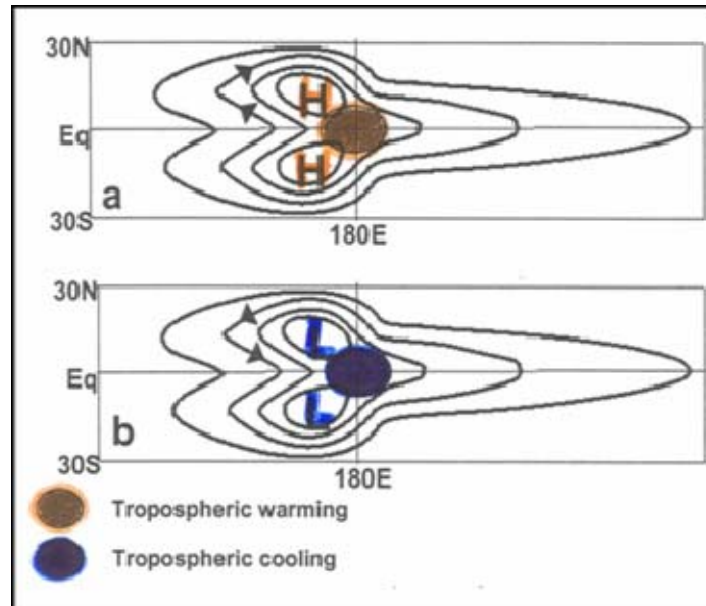


Figure 8. Upper tropospheric tropical Rossby-Kelvin wave responses to warming and cooling centered on the equator. Opposite responses occur in the lower troposphere. Note in the upper (lower) panel the anticyclones (cyclones) to the northwest and southwest of the equatorial warming (cooling) region. From Ford (2000).

## 1. El Niño Southern Oscillation

El Niño (EN) and La Niña (LN) are interannual variations of the tropical Pacific Ocean and atmosphere. EN and LN are the two phases of ENLN. ENLN has been shown to have major impacts on the climate of many regions around the globe; however, the impacts on SWA have been addressed in relatively few studies, and those studies have identified a complex relationship between ENLN and SWA. Vorhees (2006) concluded that EN and LN generate Rossby-Kelvin wave responses that impact SWA, and that seasonal variations in these responses lead to seasonal variations in the impacts on SWA. During autumn

(Oct-Nov-Dec) of an EN (LN) event, there is anomalously weak (strong) convection over the MC region. This generates a Rossby-Kelvin wave response, such that during EN (LN) an anomalous upper level cyclone (anticyclone) and low level cyclone (anticyclone) develop over southern Asia. The net result is anomalously strong (weak) moisture advection into, and high (low) precipitation in, SWA during autumn of an EN (LN) event. The same process occurs in the winter of EN and LN events, but in this season, the convective anomalies over the MC region are located further to the southeast than in autumn, leading to a shift in the circulation anomalies near and over SWA. The net result is that precipitation tends to be anomalously low (high) during winter of an EN (LN) event, the opposite of the autumn anomalies described above.

Vorhees (2006) showed that the anomalous circulations associated with the Rossby-Kelvin wave responses to the suppression of convection in the eastern IO and MC convection can create an anomalously positive influx of moisture into SWA. This increase in moisture can be an important trigger mechanism for increased precipitation. When the anomalous moisture influx occurs in conjunction with extra-tropical cyclone (ETC) activity, precipitation rates are increased. Vorhees (2006) found that the anomalous moisture advected into SWA comes from the northwest IO and nearby regions of warm air. Thus, positive precipitation anomalies were associated with positive temperature anomalies. The reverse circulation, moisture, and precipitation patterns were found by Vorhees (2006) for periods of enhanced convection over the eastern IO and MC regions. Figure 9 and Table 1 summarize these results from Vorhees (2006).

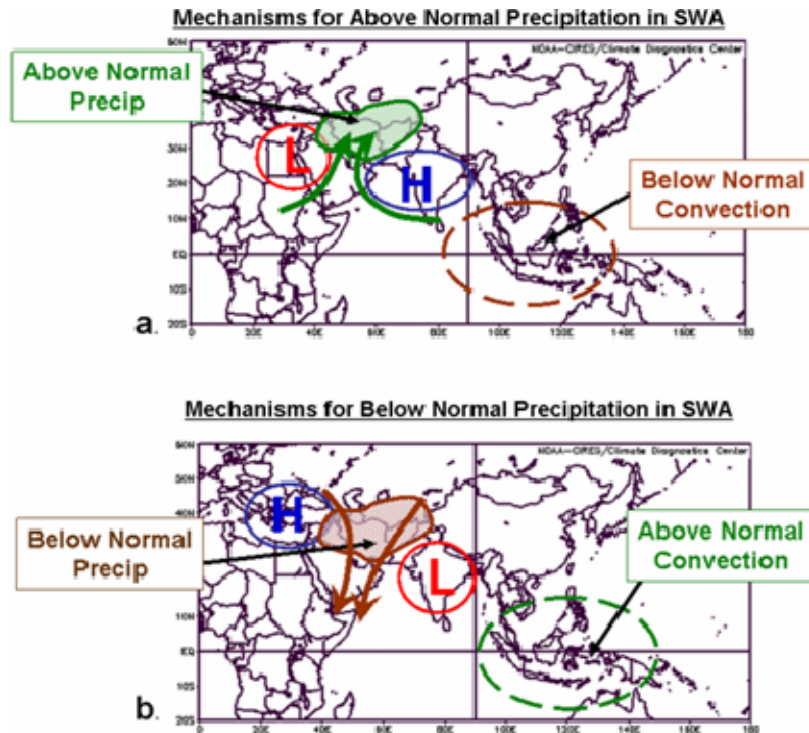


Figure 9. Schematic relationships between anomalous convection over maritime continent, circulation over SWA, and precipitation in SWA. From Vorhees (2006).

	FALL	WINTER
EN	Wet	Dry
LN	Dry	Dry/Wet
NAO +	Wet	Dry
NAO -	Dry	Wet

Table 1. Fall and winter precipitation anomalies in SWA during EN, LN, and the positive and negative phases of the NAO. Adapted from Vorhees (2006).

## 2. NAO Oscillation

The North Atlantic Oscillation (NAO) has long been recognized as one of the major features of the global climate system (Jones et al. 1997). There is more than one definition of the NAO, but it is commonly recognized as a fluctuation of atmospheric mass between the low level subtropical high centered near the Azores, the Azores High, and the low level subpolar low south and east of

Greenland, the Icelandic Low (<http://www.ldeo.columbia.edu/NAO/>, accessed 17 January 2007, Vorhees 2006, Fig. 10). These regions of mass fluctuations extend roughly zonally across the North Atlantic basin. The NAO occurs on intra- and interseasonal scales, with interannual and decadal modulations, but it is most pronounced during the Northern Hemisphere winter (Murphree 2006b). Recent studies on the NAO have proposed that this oscillation is a smaller component of a global scale oscillation called the Northern Hemisphere Annular Mode (NAM), which is sometimes referred to as the Arctic Oscillation (AO); however, debate continues as to whether this is in fact the case (Vorhees 2006).

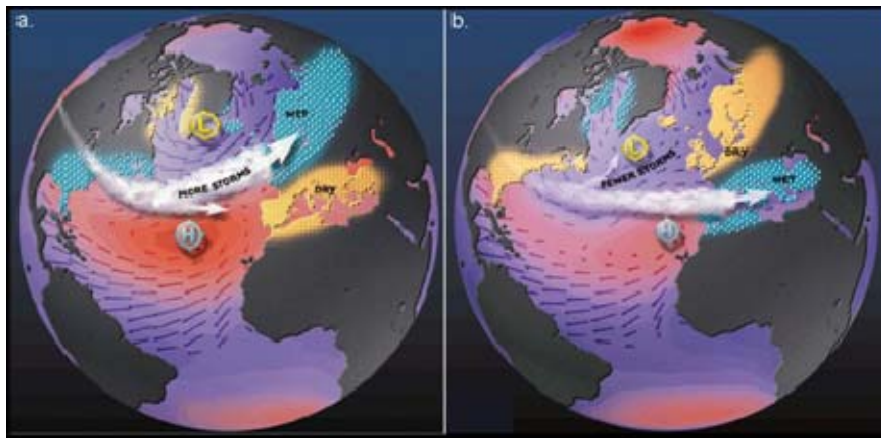


Figure 10. Left (right) panel shows the flow, storm track, and precipitation anomalies associated with the positive (negative) phase of the NAO. From <http://www.ldeo.columbia.edu/NAO/> (Accessed 17 January 2007).

The NAO has a positive (negative) phase in which both the subtropical high and the subpolar low are stronger (weaker) than normal (<http://www.ldeo.columbia.edu/NAO/>, accessed 17 January 2007). The phase of the NAO has a significant impact on the storm track, temperature, and precipitation across the Northern Atlantic and into Europe and the Mediterranean.

The positive phase of the NAO favors a storm track that is further to the north than normal, resulting in warmer and wetter (cooler and drier) conditions in northern (southern) Europe, while the negative phase produces approximately opposite effects (<http://www.ldeo.columbia.edu/NAO/>, accessed 17 January 2007).

Investigations into the influence of the NAO on SWA climate have yielded mixed results. Cullen and deMenocal (2000)) concluded through correlation analysis using the Hurrell NAO index that the NAO did not exert a significant influence on temperatures and precipitation in the region. Cullen and deMenocal (2000) concluded that the positive (negative) phase of the NAO led to the advection of colder (warmer) air around an anomalous ridge (trough) and into SWA. The same study found a negative correlation between precipitation over the Mediterranean and SWA during the winter, such that in the positive (negative) phase, precipitation over SWA decreases (increases). Trigo et al. (2002) found that in SWA the positive (negative) phase of the NAO resulted in anomalously low (high) minimum and maximum temperatures. Mariotti et al. (2005) found a positive correlation between precipitation and the Hurrell NAO index for September through November. Vorhees (2006) found that the positive (negative) phase of the NAO is associated with positive (negative) precipitation anomalies in SWA during the autumn, but that the opposite is true for the winter (Table 1).

#### **D. CLIMATE PRODUCTS CURRENTLY AVAILABLE**

The scope and magnitude of climate products are ever-evolving, due in part to new studies identify the impacts of many large scale climate variations (e.g., Vorhees 2006). Civilian operational climatology organizations apply advanced climate analysis and forecasting methods, sometimes referred to in the military climatology community as modern or smart climatology methods. Modern, or smart, climatology methods incorporate higher order statistics than the LTM, along with modern developments in research and operational climatology (Murphree 2006c). Using modern climatological techniques has enabled the civilian climate agencies to provide products that are more advanced, accurate, and effective than military climate products.

The Department of Defense (DoD) is currently exploring more modern techniques (AFCCC 2004, R. Keiss, personal communication 2006), but has yet to adopt many of the modern methods used in civilian operational climatology.



Instead, the DoD continues to promote products that were developed using traditional climate analysis methods. As a result, their products are based heavily on LTM values. The following section details the products currently available in both the military and civilian sectors.

## **1. DoD Products**

### **a. AFWA/AFCCC**

The Air Force Weather Agency (AFWA) is the headquarters field operating agency (FOA) for US Air Force weather (AFW). Per AFMAN 15-128, *Air and Space Weather Operations Roles and Responsibilities* (2004), AFWA is required to incorporate new data sources, techniques, tools, and equipment into its operations to improve its strategic-level forecasting ability. The AFWA suite of products is high-quality, but it falls short of satisfying the requirements of AFMAN 15-128 that mandates that AFWA review the National Oceanic and Atmospheric Administration (NOAA), US Navy, and foreign national climatological data resources for application to the aerospace mission. Doing so would ensure that AFWA provides statistical weather and climatological studies for engineering design, weapons systems employment, and operational planning purposes. Smart climatological methods, such as those used in the civilian sector, would help AFWA meet the requirements of AFMAN 15-128.

AFCCC, based in Asheville, NC, provides direct access to a wide range of products through their website. Popular products such as ceiling, visibility, lightning, icing potential, and thunderstorm frequency climatologies, regional and country narratives on standard meteorological and climatological regimes, and operational climatic data summaries of monthly and annual climatic data; are available to anyone who can access their website (<https://notus2.afccc.af.mil/SCISPublic/>, accessed 19 February 2007). The information may be extensive, but products are based primarily on LTMs and fail to directly account for anomalies. AFCCC is currently working towards correcting this shortfall through the efforts of its Seasonal Prediction Working Group (SWPG). The SWPG is addressing these issues by exploring climate analyses and forecasts produced by several civilian agencies, such as the Climate



Prediction Center (CPC) and the International Research Institute for Climate and Society at Columbia University (IRI).

## **2. Non DoD Products**

### **a. US Products**

(1) National Oceanic and Atmospheric Administration (NOAA). The climate products available from NOAA include climate outlooks of temperature and precipitation, experimental seasonal climate forecasts of temperature and precipitation, and monitoring of major oscillations such as ENLN (<http://www.noaa.gov/climate.html>, accessed 15 January 2007). NOAA's major sub-agencies generate and provide many of the above products and are further detailed below.

(2) Climate Prediction Center (CPC). The NOAA CPC, in Camp Springs, Maryland, provides assessments and forecasts of the impacts of short-term climate variability, emphasizing enhanced risks of weather-related extreme events, for use in mitigating losses and maximizing economic gains (<http://www.cpc.ncep.noaa.gov/>, accessed 15 January 2007). Their products are operational predictions of climate variability, real-time monitoring of climate and required data bases, and assessments of major climate anomalies. The products cover time scales from one week to several seasons (<http://www.cpc.ncep.noaa.gov/>, accessed 15 January 2007). CPC is currently producing probability forecasts with up to 12.5 month lead times for temperature and precipitation accumulation across the US. Experimental status, three-month seasonal outlooks for temperature and precipitation are now available through CPC by accessing <http://www.cpc.ncep.noaa.gov/products/predictions/90day/> (accessed 15 January 2007).

(3) Earth System Research Laboratory (ESRL). The NOAA ESRL, in Boulder, Colorado, identifies the mechanisms of climate variations on time scales ranging from a month to centuries, with the goal of developing the ability to predict important climate variations, such as ENLN and NAO, on these time scales (<http://www.noaa.gov/climate.html>, accessed 15 January 2007). ESRL currently provides experimental two-week forecasts products, which are

derived from an experimental real-time ensemble run at ESRL. A 15-member ensemble is run every day at 00 UTC using a frozen version of the operational medium-range forecast (MRF), which was operational between January and June 1998.

(4) International Research Institute for Climate and Society (IRI). IRI, located at Columbia University in Palisades, New York, deals with society's capability to understand, anticipate and manage the impacts of seasonal climate fluctuations (<http://iri.columbia.edu/>, accessed 15 January 2007). IRI generates climate monitoring and prediction products, and investigates the impacts of climate variations. IRI products address regions outside of the US, such as Southwest Asia. A seasonal climate outlook for SWA regional temperatures and precipitation for two and three month periods can be accessed through <http://iri.columbia.edu/climate/forecast/cswasia/index.html> (accessed 15 January 2007). IRI's methods for generating its products are similar to those used by CPC and ESRL.

**b. Non-US Products**

(1) The Hadley Centre for Climate Change. The Hadley Centre for Climate Change is a research subsidiary of the UK Meteorological Office (UKMO) and serves as the UK's official center for climate change research. Their centre provides in-depth information on climate change issues by monitoring and predicting global and national climate variability and change. The Hadley Centre analyses climate changes during the last 100 years, and investigates predictability of climate changes on the order of 100 years into the future (<http://www.metoffice.gov.uk/research/hadleycentre/about.html>, accessed 15 January 2007).

(2) European Centre for Medium Range Weather Forecasts (ECMWF). ECMWF is an international organization based in Reading, UK, that provides medium range weather forecast support to European meteorological organizations. The basic objectives of ECMWF are to develop numerical methods for medium-range weather forecasting, to distribute these medium-range forecasts to its customers, and to conduct research to support these

efforts. ECMWF also runs a seasonal forecasting system which provides forecasts out to six months (<http://www.ecmwf.int/about/overview/>, accessed 15 January 2007).

(3) Tokyo Climate Center (TCC). TCC is a subsidiary of the Japan Meteorological Agency (JMA) and was formed in 2002 to aid the National Meteorological and Hydrological Services agency in monitoring extreme climate events and the global climate system in the Asia-Pacific region. TCC has concluded that ENLN, the Asian Monsoon, and the Arctic Oscillation are key factors governing climate variability in the Asia-Pacific region. The TCC focus is on climate variability in the Asia-Pacific and tropical Pacific regions (<http://okdk.kishou.go.jp/about.html>, accessed 15 January 2007).

The JMA provides four kinds of long-range forecast products: a one-month forecast, a three-month seasonal outlook, a warm-season outlook, and a cold-season outlook. Using an ensemble prediction technique and empirical/statistical methods, such as canonical correlation analysis, and optimal climate normals, in conjunction with their numerical prediction system, the JMA generates probabilistic forecasts. Individual elements are forecast in an above normal, near normal, and below normal category. Currently, the JMA provides probabilistic forecasts for 500hPa geopotential heights, 850hPa temperatures, stream function, velocity potential, and surface air temperatures between 60°N and 60°S (<http://okdk.kishou.go.jp/products/model/index.html>, accessed 15 January 2007).

### **3. Tackling the Gap**

The civilian U.S. and international weather agencies are leading the way in extended range forecasts and seasonal outlooks. Their methods are advanced and their products are easily accessible to the general public. This not only suggests that great potential exists for modern climatological methods to be integrated into DoD weather, but it also highlights how large the gap is between the two sectors. It is *vital* for DoD weather to tackle this gap head-on and integrate modern climatological methods in order to present the most up-to-date climate information to decision-makers. The AFCCC/SWPG efforts, modeled

after NOAA, are a step in the right direction, but these methods need to be more widely adopted and applied throughout AFW and the Navy meteorology and Oceanography (METOC) communities.

DoD does not need to start from scratch. Incorporating and analyzing the latest data sets available from civilian organizations into existing DoD products is realistic and feasible. The National Center for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) reanalysis datasets are readily available and well suited for many DoD applications (as shown by LaJoie 2006, Stepanek 2006, and Vorhees 2006). There are limitations to these datasets, but many of these limitations are well documented. These datasets, when combined with modern analysis methods, can provide important insights into the major climate variations that impact regions of DoD interest (Vorhees 2006). This study is one example of how to do so.

#### **E. SCOPE OF THIS STUDY**

The three studies recently completed by LaJoie (2006), Stepanek (2006), and Vorhees (2006) are examples of information that must be considered by the military weather community. They highlight important climate variations that can not be ignored in politically relevant regions such as SWA. Vorhees (2006) provided a comprehensive study on the impacts of global scale climate variations on SWA. Our study is a more in-depth, statistical investigation into these impacts on Afghanistan and into the potential for forecasting these impacts. Specifically, our objectives in this study were to: (1) conduct a statistical analysis of the impacts of ENLN and NAO on Afghanistan; and (2) develop and test a statistical model for forecasting temperature and precipitation in Afghanistan.

Our hypothesis was that composite analysis and probabilistic forecast methods applied to NCEP/NCAR reanalysis data will yield effective forecasts of climate variations in Afghanistan that are more accurate than forecasts based on LTMs.

Chapter II presents our data and methods. Our results are presented in Chapter III. Chapter IV contains a summary of our results, conclusions, and suggestions for future research.

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## **II. DATA AND METHODS**

### **A. DATA**

Our primary dataset was the NCEP/NCAR reanalysis data set (Kalnay et al. 1996, Kistler et al. 1999), acquired from ESRL via its website at <http://www.cdc.noaa.gov/>. This dataset contains global analyses of land surface, ship, rawinsonde, pibal, aircraft, satellite and other data, at 2.5° latitude x 2.5° longitude horizontal resolution, at standard atmospheric levels, for 1948 through the present. A list of known problems for this data set has been compiled and is accessible via <http://www.cdc.noaa.gov/cdc/reanalysis/problems.html>.

The horizontal resolution of 2.5° latitude x 2.5° longitude is too coarse to resolve most mesoscale processes which is especially likely in regions of complicated topography. Additionally, the different reanalysis fields have different dependencies on observational data (Kalnay et al., 1996). For example, precipitation from the reanalysis is derived solely from the model fields, and is not directly tied to observations of precipitation. We chose to limit our data period for this study to 1970-2006 (37 years) to focus on data from the satellite era, and to have enough years to obtain a relatively large number of occurrences of the climate variations of interest (e.g., of EN, LN, positive NAO phase, and negative NAO phase).

### **B. CLIMATE VARIATION INDICES AND PROBABILISTIC FORECASTS**

#### **1. El Niño/La Niña**

We chose as our ENLN index the Niño 3.4 index, which monitors the three-month average of SST anomalies (measured from a 1971-2000 base period), across the Niño 3.4 region (5°N-5°S, 120°-170°W, Fig. 11; see also <http://www.weather.gov/pa/fstories/2005/0205/fs10feb2005b.php>). To identify past EN and LN events, we used Niño 3.4 SST anomaly threshold of  $\pm 0.5^{\circ}\text{C}$ . This threshold is the default threshold used by NOAA in their composite analysis techniques (Higgins et al. 2004).

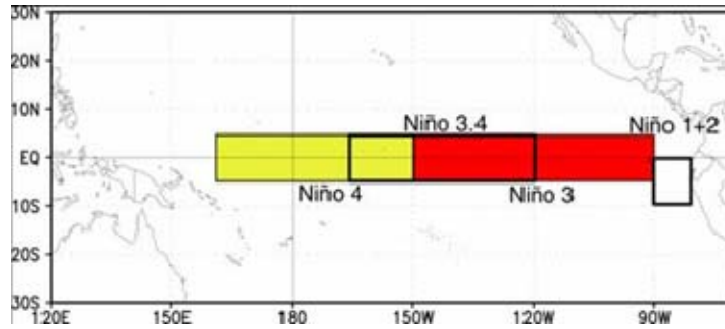


Figure 11. The four ENLN SST monitoring regions. The Niño 3.4 region lies in the middle, encompassing parts of the Niño 3 and Niño 4 regions. From <http://www.cpc.ncep.noaa.gov/> (Accessed 19 February 2007).

The Niño 3.4 monitoring index has limitations. The most important limitation is that this index monitors only SST anomalies. As found by Trenberth et al. (2001), solely monitoring SST anomalies and monitoring them in only one region of the tropical Pacific does not represent the variability in SSTs across the entire tropical Pacific. As a result, the Niño 3.4 region fails to measure the complete atmospheric response to the entirety of the SST anomalies. Therefore, this index cannot identify all of the atmospheric components that encompass an EN or LN event.

A more comprehensive representation of ENLN is found in the Multivariate ENLN Index (MEI, <http://www.cdc.noaa.gov/people/klaus.wolter/MEI/index.html>, accessed 20 March 2007). This index monitors variability across six observed variables across the tropical Pacific Ocean: sea level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. The MEI was used in the Vorhees (2006) study. However, for the forecast method used in our study, we needed a probabilistic forecast of the global scale climate variations (e.g., ENLN, NAO) thought to influence SWA. This forecast needs to be in terms of the climate variation index used to identify past occurrences of the climate variation. CPC issues ENLN forecast in terms of the Niño 3.4 index. However, no forecast (probabilistic or otherwise) of the MEI currently exists, so we were not able to use it in this study. For our study, we used the Niño 3.4 index (Fig. 12) and the probabilistic forecasts for JFM, AMJ, JAS, and OND available from CPC.



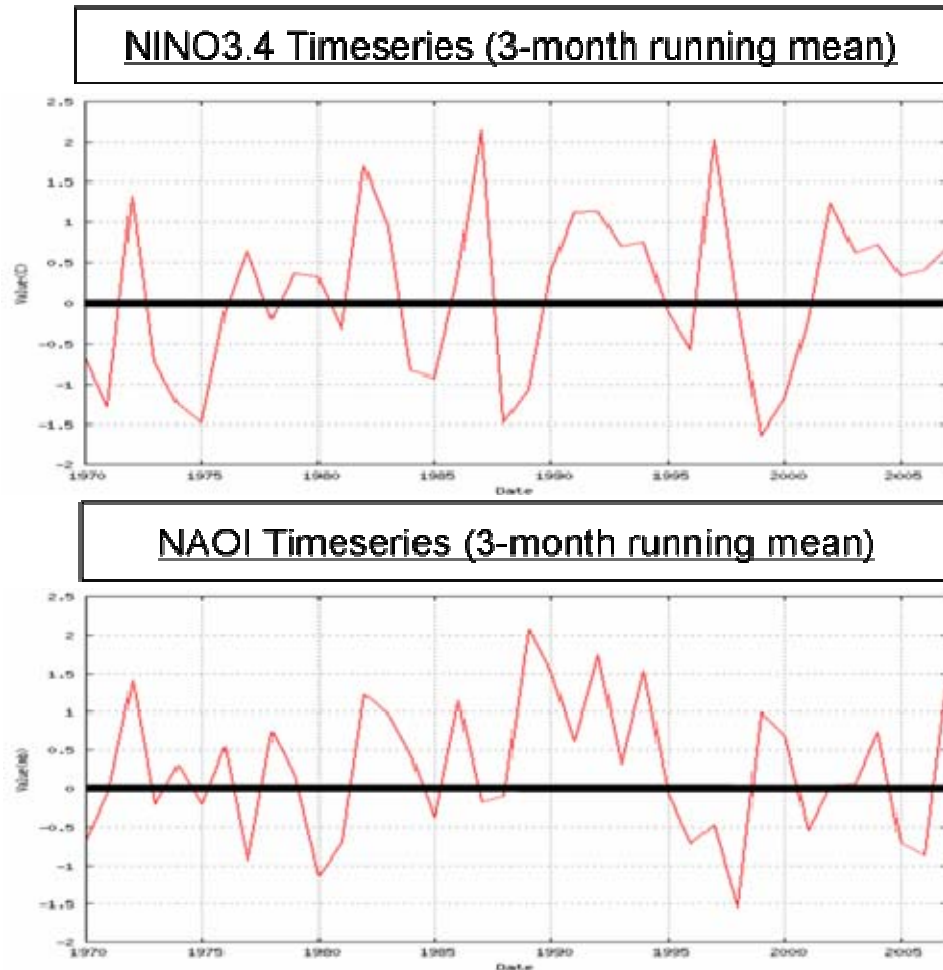


Figure 12. ENLN and NAO index timeseries used in this study. The values shown are three-month running mean index values from 1970-2006. Each index timeseries ranges from -2 to +2.5. Figures generated at <http://www.cdc.noaa.gov/Timeseries/> (Accessed 1 March 2007).

## 2. North Atlantic Oscillation

Several NAO indices, all constructed with various methods, have been used in previous studies. The older NAO indices employ a station-based method, examining SLP variability between various northern and southern stations in the North Atlantic, with the most common locations being Ponta Delgada in the Azores (37.7°N, 25.7°W) and Stykkisholmur (65.0°N, 22.8°W) in Iceland. Jones et al. (1997) recognizes these two stations as the most commonly used, but argues the case for considering other southern stations (e.g., Gibraltar, Lisbon, and San Fernando) depending on the time of year and period of record (as far

back as the 17<sup>th</sup> century for some locations). Regardless of the stations used, the station-based method is limited to using two points to represent a basin scale climate variation. This limitation led to the development of an NAO index based on rotated principal component analysis (RPCA; Barnston and Livezey 1987). This method better represents the large scale spatial pattern associated with the NAO. The RPCA based NAO index is based on gridded data across the North Atlantic region (e.g., gridded sea level pressure (SLP) data from the NCEP reanalysis dataset). Thus, it can only be constructed when such data is available (from 1948 onward). More information on the RPCA method, as well as access to CPC's monthly NAO index based on this method, is available at <http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml> (Accessed 23 January 2007). Discussions of the different methods for developing NAO indices are available from Hurrell (2003) and at <http://www.cgd.ucar.edu/cas/jhurrell/indices.html> (accessed 23 January 2007). For our study, we chose to use the CPC NAO index (Fig. 12), for consistency with our choice of the NCEP/NCAR reanalysis dataset, and with Vorhees (2006).

Currently, there is no operational probabilistic forecast of the NAO. CPC provides NAO index outlooks based on global forecasting system (GFS) 7, 10, and 14-day forecasts of 500mb geopotential heights. These forecasts are available through the CPC website: <http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml#forecast> (accessed 26 January 2007). Since these forecasts do not match the NAO index based on SLP, and do not provide probabilistic forecasts with long lead times, they were not suitable for our forecast method. To mitigate this issue, we developed a forecasting method that provides probabilities of occurrence based on the observed tendency of the oscillation to change phases from one season to the next. We determined this tendency by identifying, for each seasonal transition (e.g., autumn to winter), and for all 37 years, the change in the NAO index phase (e.g., change from positive NAO to negative NAO). From these results, we calculated the percentage of time for each of the four seasonal transitions that each of the possible transitions occurred. We then used these percentages to

produce a conditional probability forecast (e.g., the probability that if in a given autumn the NAO phase is positive that in the following winter the NAO phase will be negative). We named this forecast a tendency oscillation forecast (TOF) and used them as our probabilistic forecasts for the NAO. The seasons we used were: winter (January-March (JFM)), spring (April-June (AMJ)), summer (July-September (JAS)), and autumn (October-December (OND)). Figure 13 gives an example of how a TOF is produced.

JAS phase	Events	OND Phase	Events	Percentage
Positive	7	Positive	7	100.00%
		Neutral	0	0.00%
		Negative	0	0.00%
Neutral	23	Positive	6	26.09%
		Neutral	12	52.17%
		Negative	5	21.74%
Negative	7	Positive	0	0.00%
		Neutral	0	0.00%
		Negative	7	100.00%

**JAS EN conditions stayed EN 100% of the time into OND**

Figure 13. EN example of how a TOF is calculated. The TOF is developed by determining the percentage of time during the data period that the current phase of the oscillation stays the same or changes to another phase in the following season. For example, during the JAS season, the 7 observed EN events (over the 37 year period of our data set) remained in the EN phase 100% of the time in OND; and neutral conditions in JAS were followed by positive (EN) conditions in OND 26% of the time.

Since the TOFs use the NAO phase from one season to predict the NAO phase in the following season, the lead time for these forecasts is zero months. However, in practice, the preceding season's phase can generally be determined about two weeks prior to the beginning of the valid period. In addition, since the valid period is three months long, the lead time with respect to the center of the valid period is six weeks, making the effective lead time greater than zero.

## C. METHODS

### 1. Overview

Our method involves an eight-step composite analysis and forecast (CAF) process outlined in Fig. 14.



Figure 14. CAF method. Steps 1-7 represent the historical composite analysis portion of the method. Step 8a represents the use of LTMs to generate a forecast, if the results from step 7 are not statistically significant. If these results are statistically significant, then step 8b is taken. This step represents the application of: (a) the results from step 7 and (b) a probabilistic forecast of the predictor index to generate a probabilistic forecast of the predictands.

For step 1, we selected Afghanistan as our spatial scale and region of interest, based on the results of Vorhees (2006) and the importance of this region for DoD operations. For step 2, we selected the four seasons as our temporal scale, because seasonal scale planning for all four seasons is an important part of military planning. For step 3, we chose ENLN and NAO as our climate variations, and as our predictors, based on Vorhees (2006) and the climate indices and forecasts available for these variations. For step 4, we chose 850hPa temperature (approximately the same as surface temperature for most of Afghanistan) and precipitation rate (PR) in Afghanistan as our predictands

because these variables have widespread military impacts. For step 5, we chose the NCEP/NCAR reanalysis dataset, for the reasons discussed in Chapter II, section A. Steps 6-8 are more involved and are described in the following sections.

## **2. Composite Analysis – Step 6**

In this step, we determined the historical distribution of the predictands with respect to the predictors. For example, we determined the number of times in the 37 year period that above normal PRs were observed during the positive phase of the NAO. We performed this analysis for all three phases of ENLN (EN, neutral, LN) and all three phases of the NAO (positive, neutral, negative), for all four seasons (JFM, AMJ, JAS, OND), using data from our 37 year study period, 1970-2006. This step provides a historical analysis of past conditions during a particular phase of a climate variation known to be correlated to the region. Prior to our study, this information was not available for SWA. The results of this composite analysis are useful by themselves, and are an important addition to the LTM values of the predictands, because they provide insight into how the predictands are affected by the predictors – that is, how Afghanistan temperature and PR have historically been affected by ENLN and the NAO.

To conduct this step, we first defined Afghanistan as the area between 30.0-37.5°N latitude and 60-75°E longitude (See Fig. 3). This area encompasses nine NCEP/NCAR reanalysis grid points, and a portion of northern Pakistan. For this region, we constructed a monthly time series of the predictors, 850hPa temperatures and precipitation rate (PR) for Afghanistan, for 1970-2006 (Figs 16-17) using the ESRL time series construction web site (<http://www.cdc.noaa.gov/Timeseries/>; accessed 27 January 2007).

We then performed a localized composite analysis based on these time series. To perform this analysis, we used a process developed by NOAA to compute historical US station composite analyses and provide experimental composite analysis seasonal forecasts based on ENLN events (<http://www.nws.noaa.gov/om/csd/pds/OpsCourse/PCU4.3Part2.htm>, accessed 26 January 2007). We adapted the NOAA process for our region, period,

predictors, and predictands. This process involved classifying the seasonal predictand values according to three terciles: the upper third or above normal (AN) tercile, the middle third or near normal (NN) tercile, and the bottom third or below normal (BN) tercile. The 37 individual samples of each of the four seasons are evenly distributed among the terciles, so that there are an equal (or nearly equal) number of individual seasons in each tercile. So, for the 37 JFMs, there would be, for example, 12 JFMs in AN, 13 JFMs in NN, and 12 JFMs in BN. The net result is a determination of the tercile thresholds for each predictand.

The predictand values for each season were then organized according to the corresponding observed phase of the predictors (e.g., EN, neutral, and LN phases for ENLN). Thus, for example, the predictand value for each JFM was categorized as occurring during an EN, neutral, or LN period. From this, the distribution of the predictand relative to the predictor was determined. For example, the number of occurrences of AN, NN, and BN PR during EN was determined. The net result was that for each season and each phase of the predictors (ENLN and NAO), we determined the number of observed occurrences of AN, NN, and BN predictand values during the 37 year study period. This result describes the distribution of the predictands relative to the predictors and is sometimes referred to as the relative frequency distribution.

### **3. Statistical Significance – Step 7**

The results of step 6 were then analyzed to determine their statistical significance. Statistically significant results would indicate that the relationships described by the results were unlikely to be arrived at by chance. In order to assess whether the results were statistically significant (SS), we performed a risk analysis using a geometric distribution. This step describes the probability distribution between all possible outcomes of a category within the three phases of the climate variations (positive, neutral, negative). For the NOAA composite analysis process, the default is a 90% confidence level (the same as a 10% significance level); with the significance being determined by two separate one-tailed hypothesis tests. If the number of observed BN, NN, or AN occurrences during the positive, neutral, negative phase of the climate variation falls within the

left (right) tail of either of the hypothesis tests, the results are statistically significant. This means that there is at least a 90% level of confidence in our results being attributed to the climate variation and not to chance.

#### **4. Forecast – Step 8**

Once the results of step 7 were obtained, we developed a forecast. If the step 7 results were not SS, then we performed step 8a and used the LTMs as the forecast values. If the results were SS, we then produced a composite analysis forecast (CAF). A CAF describes the conditional probability of occurrence of a given value of the predictand based on a probabilistic forecast of the phase of the predictand (e.g., the probability of AN PR given a forecast of ENLN) (<http://meted.ucar.edu/climate/composite/print.htm>, accessed 25 July 2006). A CAF is generated by multiplying the observed relative distribution of the predictand for each tercile category (AN, NN, BN) times the corresponding category of the probabilistic forecast of the predictor (EN, neutral, LN for ENLN; positive, neutral, negative for NAO). Figure 15 shows an example of this calculation for a CAF of above normal (AN) conditions in Afghanistan. Note that this calculation involves all three predictand categories and all three corresponding predictor categories. This is because there is, in general, a non-zero probability of each of the three predictor categories occurring. Thus, all three of these probabilities must be accounted for by multiplying it by the corresponding predictand distribution category. The resulting forecast shows the probability of AN, NN, and BN conditions occurring with the total probability for all three categories being 100%. For example, a CAF might give a 10% probability of AN, a 20% probability of NN, and a 70% probability of BN conditions.

We plotted the results of our CAF calculations to give graphical forecasts (e.g., pie charts split into the three possible outcomes, AN, NN, and BN conditions). These probabilistic forecasts are an important step beyond the historical composite analysis results from step 6. However, the CAF step (step 8b) is only taken when SS results have been obtained from step 7.

$$\begin{array}{c}
 \text{Above} \\
 P_{\text{station above}} = P_{\text{station above / El Niño}} \times P_{\text{Nino3.4 above}} + P_{\text{station above / Neutral}} \times P_{\text{Nino3.4 near}} + P_{\text{station above / La Niña}} \times P_{\text{Nino3.4 below}}
 \end{array}$$

Figure 15. Equation used to calculate the composite analysis forecast (CAF) for AN conditions associated with EN. In words, this equation translates to taking: “the probability of being in the above-normal category given El Niño” times the “forecasted probability of Niño 3.4 being in above normal category” plus the “probability of being in the above-normal category given neutral” times the “forecasted probability of Niño 3.4 being in the near-normal category” plus the “probability of being in the above-normal category given La Niña” times the “forecasted probability of Niño 3.4 being in the below-normal category”. (cf. <http://meted.ucar.edu/climate/composite/print.htm>, Accessed 1 March 2007).

All of our composite analyses and generations of CAFs were done using Excel spreadsheets.



### **III. RESULTS**

#### **A. OVERVIEW OF RESULTS**

Our results indicate that both ENLN and NAO have statistically significant relationships with 850hPa temperature and PR in Afghanistan. Statistically significant ENLN precipitation results were found in all four seasons, while statistically significant results for temperature occurred only in OND. Autumn had the largest number of statistically significant ENLN results of all the seasons. This may be due to the frequent passage of ETCs at this time of year, combined with the relatively close location of the anomalous MC convection in autumn during ENLN, as discussed by Vorhees (2006). There were a larger number of statistically significant NAO results than for ENLN, as well as a more consistent distribution of SS results throughout the seasons. Statistically significant NAO precipitation results were found in all but the JAS season. Statistically significant NAO temperature results were found in all but the JFM season. Like ENLN, autumn was the season with the largest number of statistically significant results. This may be due in part to autumn being the season in which Afghanistan receives a relatively large number of ETCs and relatively high precipitation. The subsequent sections of this chapter describe our results in detail.

#### **B. SEASONAL TIMESERIES**

The historical timeseries of 850hPa temperature and precipitation rate for Afghanistan constructed for this study are shown in Figs. 16-17. Due to the large seasonal variations in these two variables, and the need to highlight interannual variations in these variables, we have used different vertical scales for each season. This makes it more difficult to compare the seasons, but we feel this is acceptable, since the focus of this study is on variations in a given season from one year to the next, rather than on an analysis of the seasonal cycle.

Fig. 16 shows that the highest temperatures were observed during JAS (~25°C). The lowest temperatures were observed during JFM (~3°C). The approximate ranges are: JFM: 3°C-10°C; AMJ: 18.5°C-22.5°C; JAS: 21.5°C-

26°C; OND: 8-13.5°C. All four seasons show large interannual variability, indicated by the large fluctuations between high and low values occurring on time scales of 1-5 years. JFM, JAS, and OND all exhibit clear long term upward trends since about 1970, suggestive of decadal or longer period variations (e.g., global warming). All seasons show either no trend or downward trends prior to about 1970. This may be due to natural long term climate variability and/or differences due to extensive satellite data being available only from the 1970s onward.

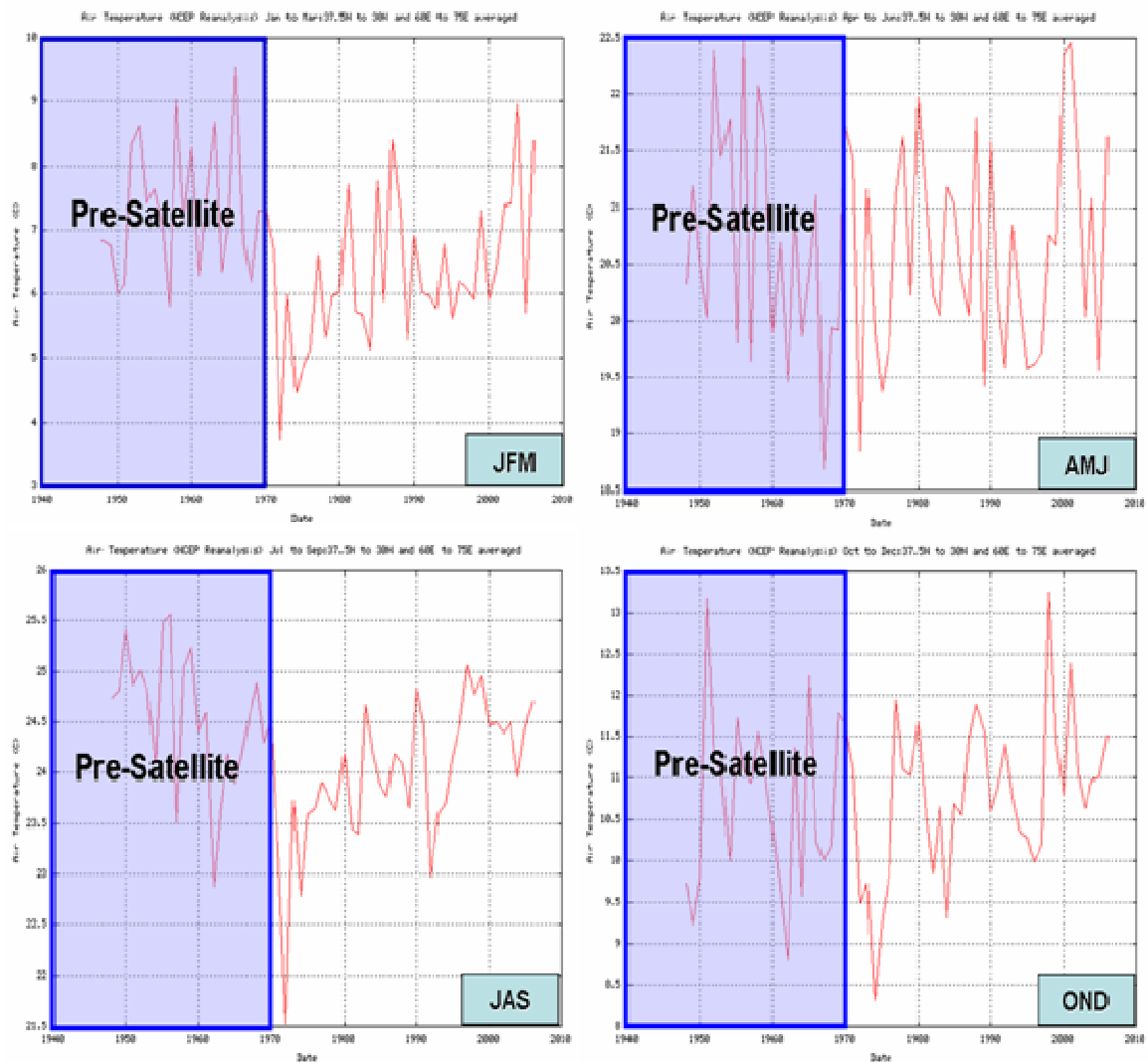


Figure 16. Seasonal timeseries of Afghanistan 850hPa temperature (°C). The period before 1970 is shaded blue to indicate pre-satellite data that was not used in this study. Figures generated at <http://www.cdc.noaa.gov/Timeseries> (Accessed 28 February 2007).

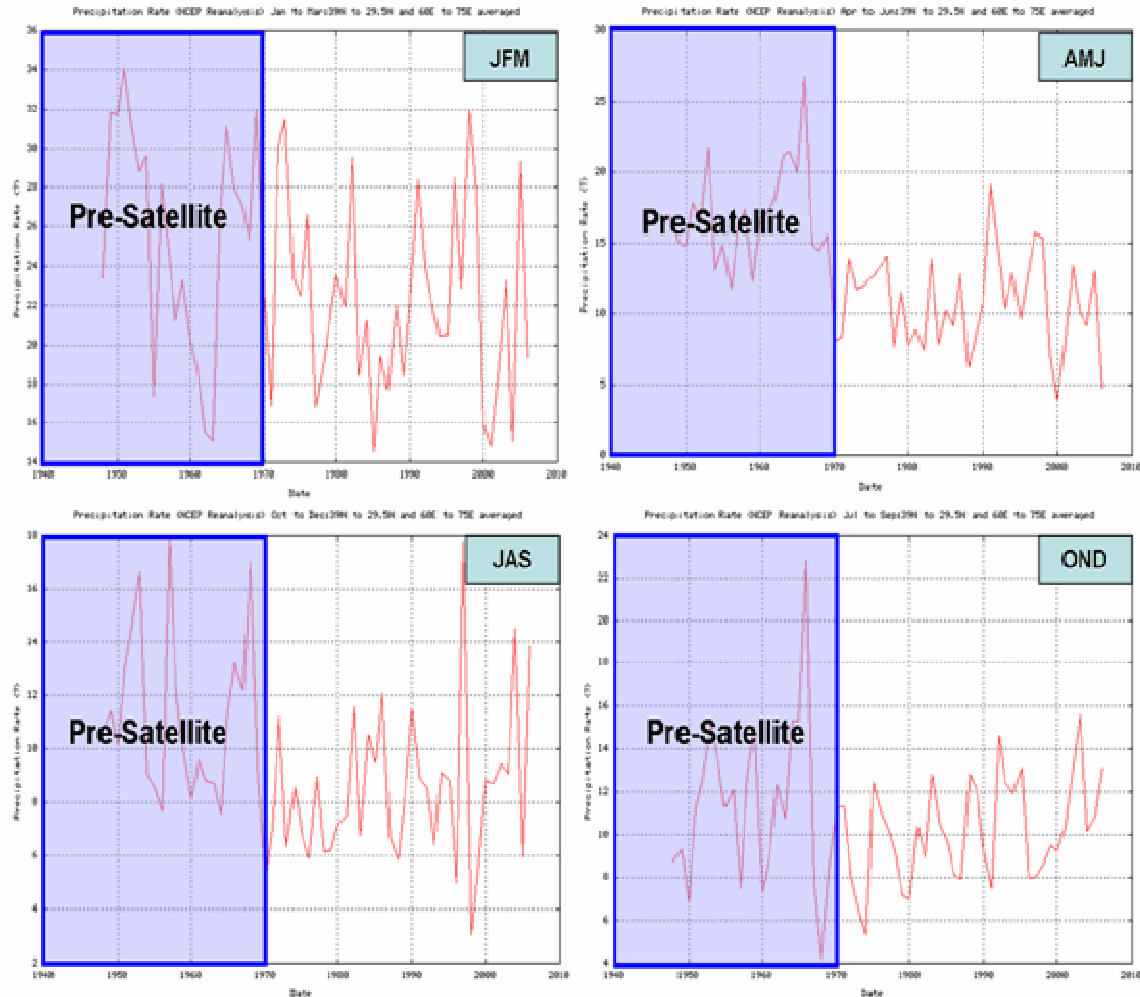


Figure 17. Seasonal timeseries of Afghanistan surface precipitation rate (mm/day). The period before 1970 is shaded blue to indicate pre-satellite data that was not used in this study. Figures generated at <http://www.cdc.noaa.gov/Timeseries> (Accessed 28 February 2007).

Fig. 17 shows that the highest PR tends to occur in JFM and the lowest in JAS. The approximate PR ranges are: JFM: 14-36 mm/day; AMJ: 0-30 mm/day; JAS: 2-18 mm/day; OND: 4-24 mm/day. All four seasons show large interannual variability, indicated by the large fluctuations between high and low values occurring on time scales of 1-5 years. Unlike the temperature timeseries, the PR timeseries shows no consistent and pronounced decadal or longer term trend across the seasons before or since 1970.

### C. FORECASTS OF PREDICTORS

Examples of the probabilistic forecasts of the predictors (ENLN and NAO) are shown in Figs. 18-19. The ENLN forecasts (Fig. 18) were the probabilistic Nino 3.4 forecasts generated by CPC and available at <http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENLN/sstcon34.txt>. (Accessed 1 March 2007). For this study, we used the running 0.5 month lead time forecasts for JFM, AMJ, JAS, and OND CPC.

<b>CPC Nino 3.4 Probabilistic Forecast</b>				
<b>Valid 2/2007</b>				
	<b>Lead Month</b>	<b>BELOW</b>	<b>NORMAL</b>	<b>ABOVE</b>
<b>MAM</b>	0.5	0.014	0.769	0.217
<b>AMJ</b>	1.5	0.046	0.686	0.269
<b>MJJ</b>	2.5	0.098	0.621	0.281
<b>JJA</b>	3.5	0.146	0.553	0.301
<b>JAS</b>	4.5	0.159	0.544	0.296
<b>ASO</b>	5.5	0.197	0.499	0.305
<b>SON</b>	6.5	0.236	0.432	0.332
<b>OND</b>	7.5	0.264	0.407	0.329
<b>NDJ</b>	8.5	0.278	0.37	0.352
<b>DJF</b>	9.5	0.295	0.376	0.329
<b>JFM</b>	10.5	0.275	0.429	0.297
<b>FMA</b>	11.5	0.196	0.539	0.265
<b>MAM</b>	12.5	0.126	0.616	0.257

Figure 18. Example of CPC Niño 3.4 seasonal probabilistic forecasts issued February 2007. The valid d seasons are shown in the left column. The probabilities of above normal, normal, and below normal Nino 3.4 values are shown in the three right columns. Blue shading indicates the four seasons we investigated in this study. Data from CPC (<http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENLN/sstcon34.txt>) (Accessed 1 March 2007).

JFM NAOI TENDENCY FCST					AMJ NAOI TENDENCY FCST				
Positive	10	Positive	7	0.7	Positive	22	Positive	9	0.409091
		Neutral	1	0.1			Neutral	9	0.409091
		Negative	2	0.2			Negative	4	0.181818
Neutral	16	Positive	9	0.5625	Neutral	8	Positive	1	0.125
		Neutral	4	0.25			Neutral	5	0.625
		Negative	3	0.1875			Negative	2	0.25
Negative	10	Positive	6	0.6	Negative	7	Positive	2	0.285714
		Neutral	3	0.3			Neutral	2	0.285714
		Negative	1	0.1			Negative	3	0.428571
JAS NAOI TENDENCY FCST					OND NAOI TENDENCY FCST				
Positive	12	Positive	2	0.166667	Positive	12	Positive	4	0.333333
		Neutral	7	0.583333			Neutral	6	0.5
		Negative	3	0.25			Negative	2	0.166667
Neutral	16	Positive	5	0.3125	Neutral	15	Positive	4	0.266667
		Neutral	5	0.3125			Neutral	4	0.266667
		Negative	6	0.375			Negative	7	0.466667
Negative	9	Positive	5	0.555556	Negative	10	Positive	2	0.2
		Neutral	3	0.333333			Neutral	6	0.6
		Negative	1	0.111111			Negative	2	0.2

Figure 19. Seasonal tendency oscillation forecasts (TOFs) of the NAO phase developed for this study. The title over each of the four panels shows the season immediately prior to the season for which the forecast was valid. The first column (counting from the left side of each panel) indicates the NAO phase for that preceding season. The second column shows the number of the preceding seasons in which the phase shown in the first column occurred. The third column shows the phase of the succeeding season for which the forecast was valid. The fourth column shows the number of the succeeding seasons in which the phase shown in the third column occurred. The fifth column shows the percentage of the succeeding seasons in which the phase shown in the third column occurred. For example, the AMJ panel (upper right) shows the positive NAO phase occurred in 22 of the 37 AMJ periods during the 37 year study period (1970-2006). In 9 (41%) of the succeeding JAS periods, the NAO phase stayed positive; in 9 (41%) of the succeeding JAS periods, the NAO phase switched from positive to neutral; and in 4 (18%) of the succeeding JAS periods, the NAO switched from positive to negative.

#### D. COMPOSITE ANALYSIS RESULTS

Our composite analysis results (the results from step 6 in Fig. 14) are displayed in bar charts, an example of which is shown in Fig. 20. The key features of this bar chart are indicated by the arrows, and colored circles and boxes. The title indicates the period, season, predictor, predictand, and region (1970-2006, OND, ENLN, 850hPa temperature, and Afghanistan, in this case). The orange box indicates the phase of the climate variation predictor (ENLN in

this case). The yellow bracket indicates the vertical scale for the percent occurrence of the predictand (850hPa temperature in this case). The red, gray, and blue bars in the bar chart show graphically the percent occurrence of AN, NN, and BN predictand cases, respectively. There is one set of red, gray, and blue bars for each of the three predictor phases (EN, neutral, LN). The bold black outline of the bar indicates a statistically significant result. The table below the figure shows in tabular form the information in the bar chart.

As an example, in Fig. 20, the leftmost red bar and the upper right cell of the table show that there were above normal temperatures in 23.1% of the OND periods that occurred during EN events. The black arrow indicates that the only statistically significant result were the below normal temperatures that occurred in 8.3% of the OND periods during neutral ENLN events. This statistically significant result indicates that for this region, season, predictor, and predictand, composite analysis forecasts (CAFs) are warranted and would be expected to provide an improvement over forecasts based on LTMs.

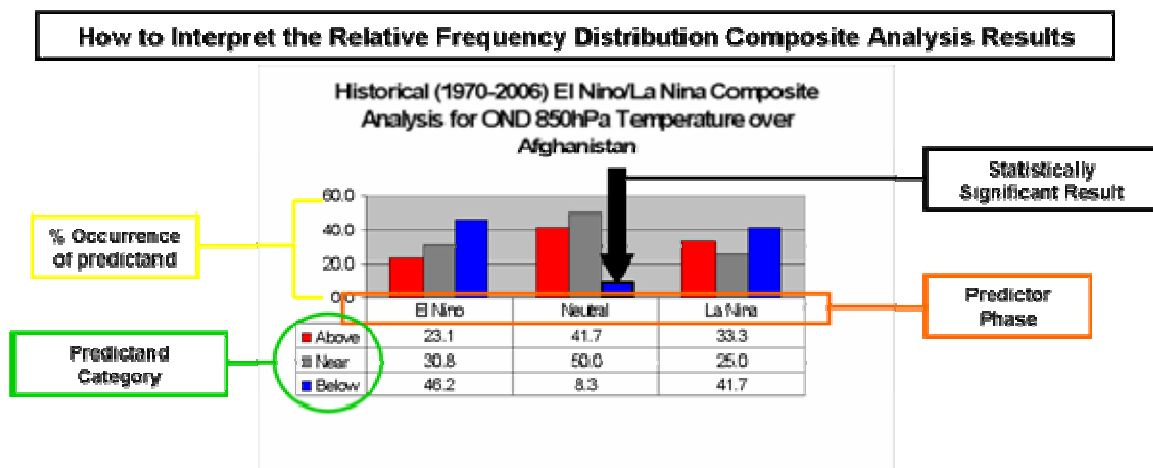


Figure 20. An example of the bar chart graphics used to present our composite analysis results. See main text for details.

Figure 21 shows the historical composite analysis results for OND PR and 850hPa temperatures for Afghanistan during the three NAO phases. The only statistically significant PR results shown in this figure are for BN PR during neutral NAO periods (BN PR occurred during 23% of the ONDs during neutral

NAO periods). The SS 850hPa temperature results are for BN during positive NAO, AN during neutral NAO, and AN and BN during negative NAO. Comparison of the two panels in Fig. 21 indicates some interesting relationships between PR and temperature. For example, during negative NAO, there is a tendency for below normal PR and below normal temperature.

The OND season had the largest number of SS temperature results for the NAO. The composite analysis identified four statistically significant results across all NAO phases. 99.7% statistical significance for BN 850hPa temperatures during positive NAO phases; 93.4% statistical significance for AN 850hPa temperatures during neutral NAO phases; 92.3% statistical significance for AN 850hPa temperatures during negative NAO phases; and 96.2% statistical significance for BN 850hPa temperatures also during negative NAO phases. These results provide excellent information for commanders. Statistical significance associated with 850hPa temperatures during the NAO suggests that these results are directly linked to the climate variation, with a very small possibility that these results were obtained by chance.

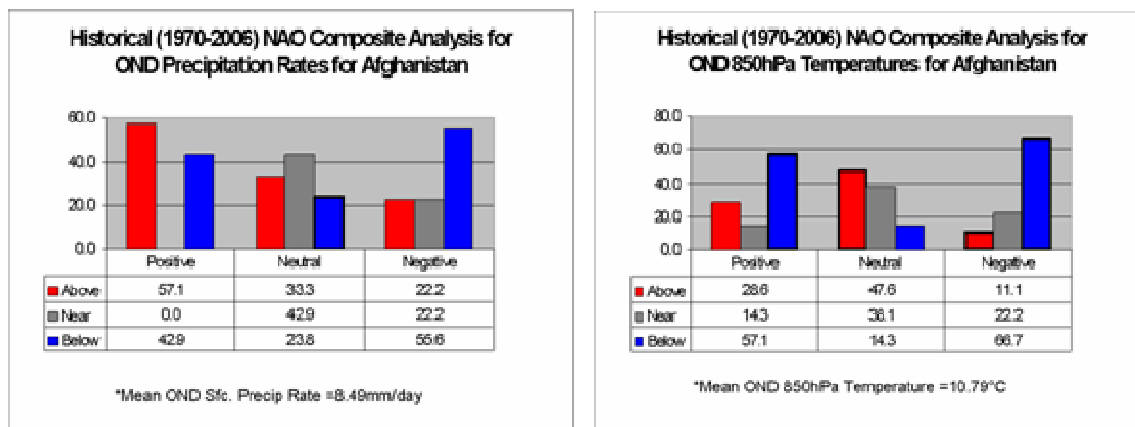


Figure 21. OND relative frequency distribution for Afghanistan PR and 850hPa temperature during NAO.

Because of the SS results for OND shown in Fig. 21, the CAF process was applied to develop forecasts of PR and temperature. These forecasts were based on the TOFs of the NAO phase during JAS (the preceding season). Examples of these forecasts are shown in Figs. 22 and 23. The most striking forecast is for a

50% probability of BN, 26% probability of AN, and 24% probability of NN 850hPa temperatures, in Afghanistan during an OND for which neutral NAO conditions are forecasted, (middle panel of Fig. 23).

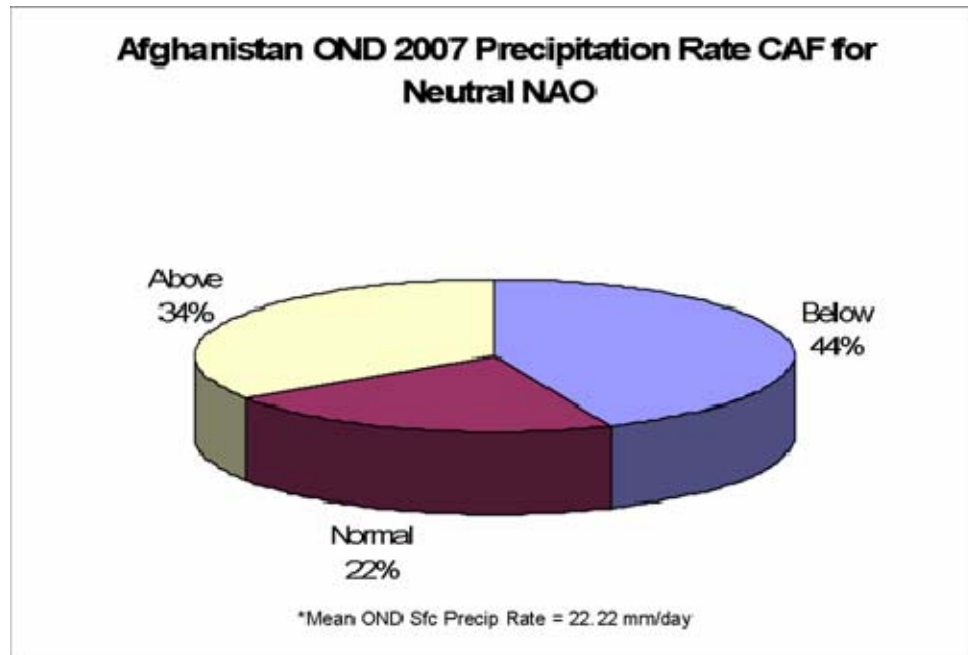


Figure 22. CAF for PR in OND during neutral NAO. Based on this forecast, BN PRs are most likely to occur. This forecast is for only one NAO phase. However, given the SS results for OND PR shown in Fig. 19, the CAF process would be applied in OND for all forecasted phases of the NAO.

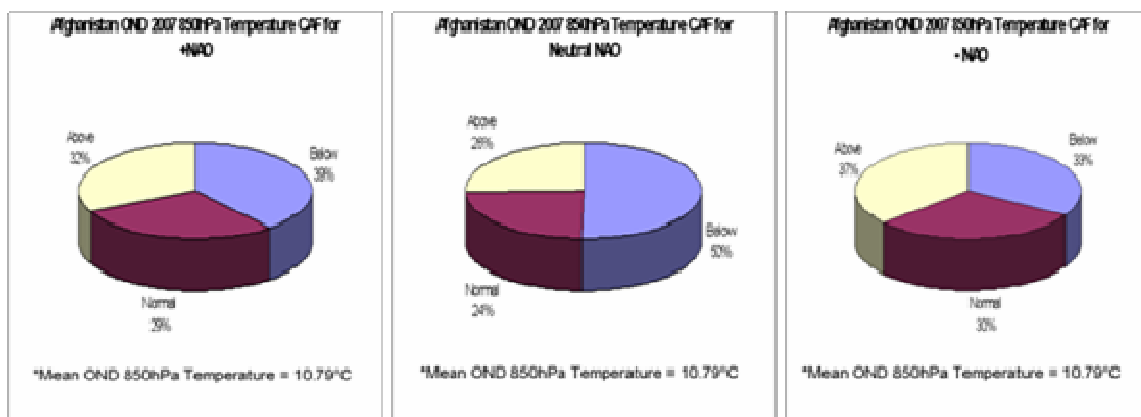


Figure 23. CAFs for 850hPa temperature in OND during all NAO phases. This forecast shows for example, the following probabilities: 39% probability of BN during positive NAO; 50% probability of BN during neutral NAO.



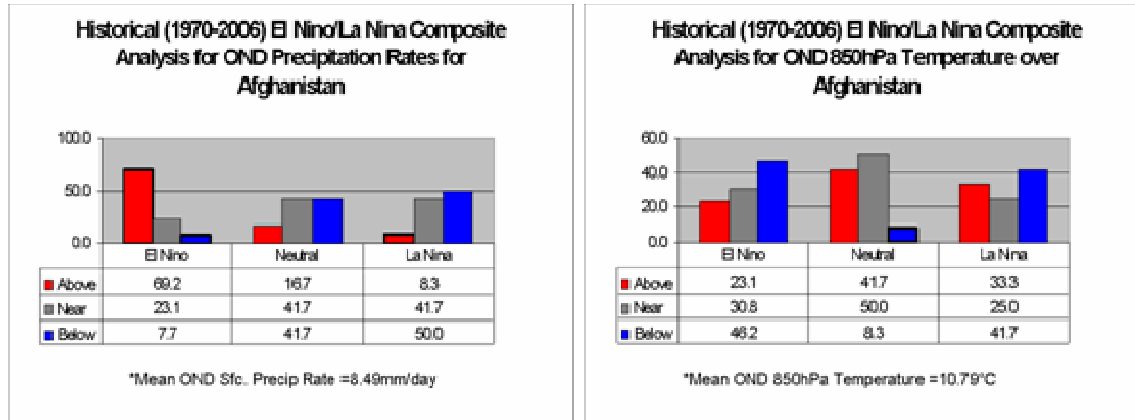


Figure 24. OND relative frequency distribution for Afghanistan PR and 850hPa temperature during ENLN.

Figure 24 is the same as Fig. 21 but for ENLN instead of NAO. In the PR distribution, there is an opposite pattern in the EN and LN phases, where AN PRs dominate during EN and BN PRs dominate during LN. This pattern is the same pattern identified in Vorhees (2006), where autumn precipitation over SWA was found to be anomalously higher during an EN and anomalously lower during a LN. A forecaster can use this information to conclude, for example, that in OND, AN precipitation is more (less) likely in Afghanistan during a concurrent EN (LN) event.

Three statistically significant results were identified for OND ENLN PR. An impressive 99.9% statistical significance was identified for AN PR during EN; 98.1% statistical significance was identified for BN PR during EN; and 96.9% statistical significance was identified for AN PR during LN. These statistical significance results confirm the Vorhees (2006) findings for PR over SWA. Based on these SS results, the CAF method was applied to OND PR for ENLN (e.g., Fig. 25).

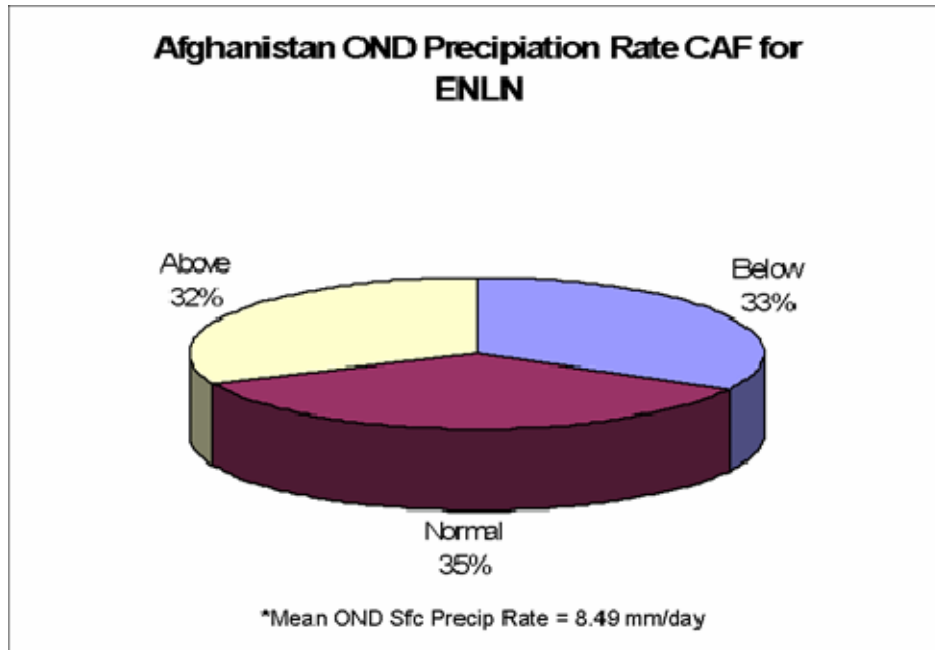


Figure 25. CAF for PR in OND for the observed ENLN phase. Based on this forecast, there is a 35% probability of a NN PR.

Fig. 24 shows that during EN, 850hPa temperature tends to be BN while PR tends to be AN. This indicates that during EN, conditions tend to be unusually wet (or snowy) and cold. These results differ from the relationship between PR and temperatures in Vorhees (2006) where a warm-wet relationship was identified for SWA during autumn of EN events. We identified 96.8% statistical significance for BN 850hPa temperatures during the neutral ENLN phase. BN temperatures occurred only 8.3% of the time in OND during neutral ENLN phases. A forecaster can therefore conclude that the dynamical processes driving a neutral ENLN phase during OND are not likely to lead to BN temperatures in Afghanistan. Although only one statistical significance result was identified in 850hPa temperatures during ENLN, the CAF method was still applicable; the lone statistical significance result for BN 850hPa temperatures during neutral ENLN concludes that there is measurable confidence that the dynamical patterns and processes driving this ENLN phase are responsible for these impacts on the regional temperatures. The CAF for this scenario can be seen in Figure 26.

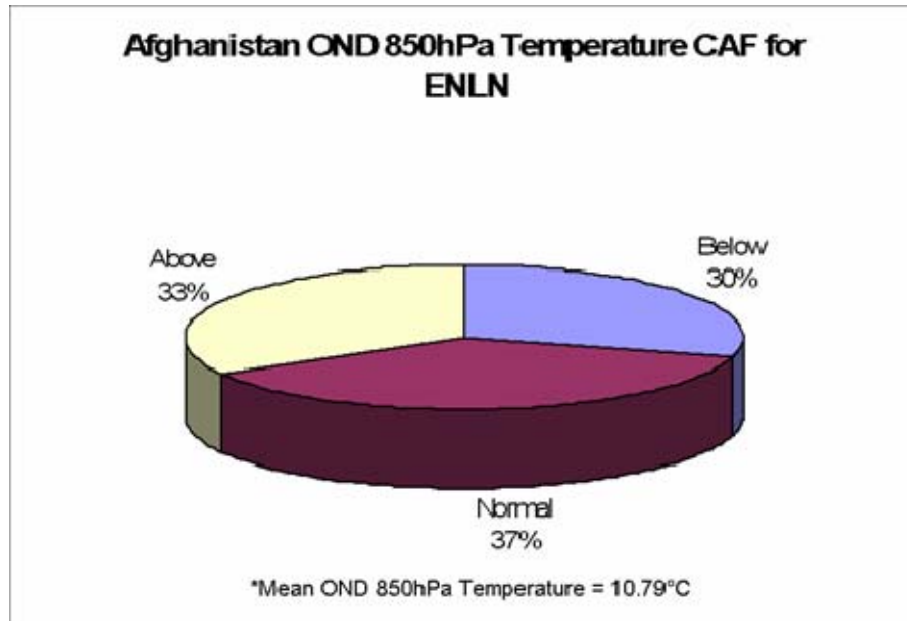


Figure 26. Probabilistic forecast for in OND during ENLN. Here, the CAF method is applied using the CPC Niño 3.4 Probabilistic Forecast for OND (see Fig. 21). Based on this forecast, NN PRs are forecasted to occur (37%) in OND 2007. CAF for 850hPa temperatures in OND for the observed phase of ENLN. Based on this forecast, there is a 37% probability of a NN temperatures.

Figure 27 illustrates the composite analysis results for AMJ PR and 850hPa temperatures for Afghanistan during the NAO. In the PR distribution, there are a high number of AN PR occurrences (80%) as compared to NN (0%) and BN PR (20%). A forecaster can therefore conclude that extreme events are more likely than NN conditions in Afghanistan during positive NAO events. AN PR also dominates the negative NAO phase (50%). A forecaster can conclude that BN precipitation occurs less often during a negative NAO. The neutral NAO phase category has an unlikely distribution, with BN PR occurring most frequently (42.3%); therefore, NN conditions are likely influenced by an additional dynamical process that could not be identified through our historical composite analysis.

We identified 95.7% SS for AN PR during positive NAO. Recalling that AN PR occurred most often in this phase category, a forecaster can therefore inform commanders that AN precipitation events occur more often during a positive

NAO over Afghanistan. We employed the CAF method to generate a probabilistic forecast for AMJ PR for Afghanistan during each NAO phase (Fig. 28).

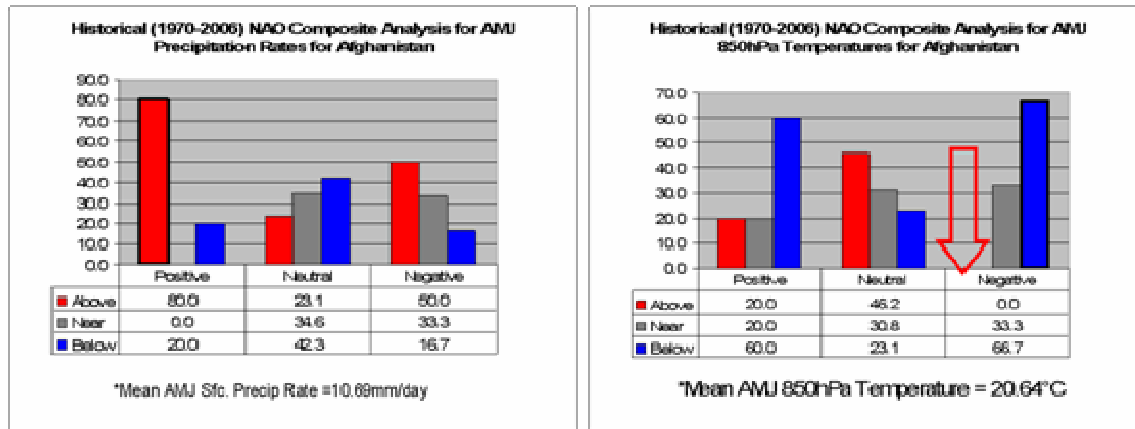


Figure 27. Relative frequency distribution for Afghanistan PR and 850hPa temperature events for AMJ observed during NAO phases. The statistical significance associated with the temperatures for AMJ is highlighted by the red arrow over the AN category, where there were zero occurrences over the period.

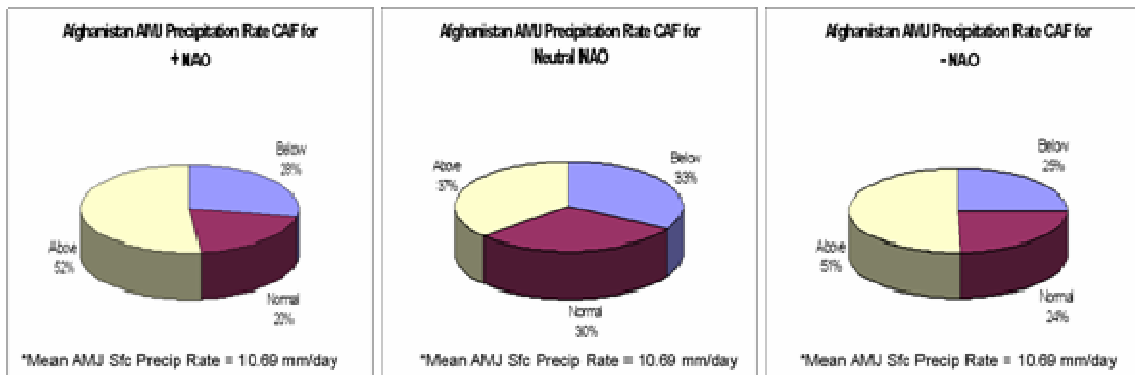


Figure 28. Probabilistic forecast for PR in AMJ for all NAO phases. The CAF method is applied using TOF probabilities. Based on this forecast, AN PRs are forecasted to occur during +NAO (52%); AN PRs are forecasted to occur during neutral NAO (37%); and AN PRs are most likely to occur during a negative NAO (51%).

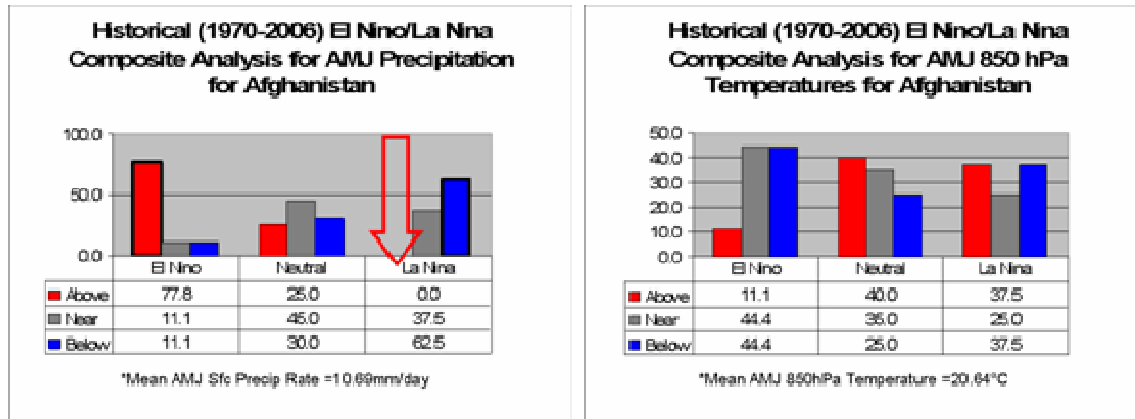


Figure 29. Relative frequency distribution for Afghanistan PR and 850hPa temperature events for AMJ observed during ENLN phases. The statistical significance associated with the PR for AMJ is highlighted by the red arrow over the AN category, where there were zero occurrences over the period.

Figure 29 illustrates the composite analysis results for AMJ PR and 850hPa temperatures for Afghanistan during the ENLN. In the PR distribution, there is a somewhat opposite pattern between the EN and LN phases. AN PRs were observed the majority of the time (77.8%) during EN, while BN PRs were observed most often (62.5%). The neutral phase illustrates that NN conditions were observed most often (45%). As AMJ is still a fairly active season for Afghanistan, a forecaster can use this information to provide commanders with continued precipitation information throughout the spring season. AN precipitation occurs more often during an EN in Afghanistan, with BN precipitation occurring less often. Anomalously high precipitation events were not observed during a LN in Afghanistan between 1970 and 2006; therefore, the potential is greatest for anomalously low precipitation over Afghanistan during LN events. Likewise, NN conditions can be anticipated during the neutral ENLN.

We identified three statistically significant results during our investigation of ENLN impacts on Afghanistan PR; this is the same number of statistically significant PR results observed during OND; this indicates that the Afghanistan spring season is just as vulnerable to ENLN impacts as the autumn season. We identified 98% statistical significance with AN PRs during EN, a 97.2% statistical significance with AN PR during LN, and a 94.6% statistical significance with BN

PR during LN. These statistical significance results demonstrate high levels of confidence in the relationship between ENLN and PR impacts in Afghanistan. For example, the lack of AN PR events during LN is most likely a result of the dynamical processes driving ENLN. From these results, a forecaster can confidently convey that anomalously high precipitation is most likely during EN, and that anomalously low precipitation is most likely during LN. The CAF method was applied to 850hPa temperatures for AMJ during ENLN (Fig. 30).

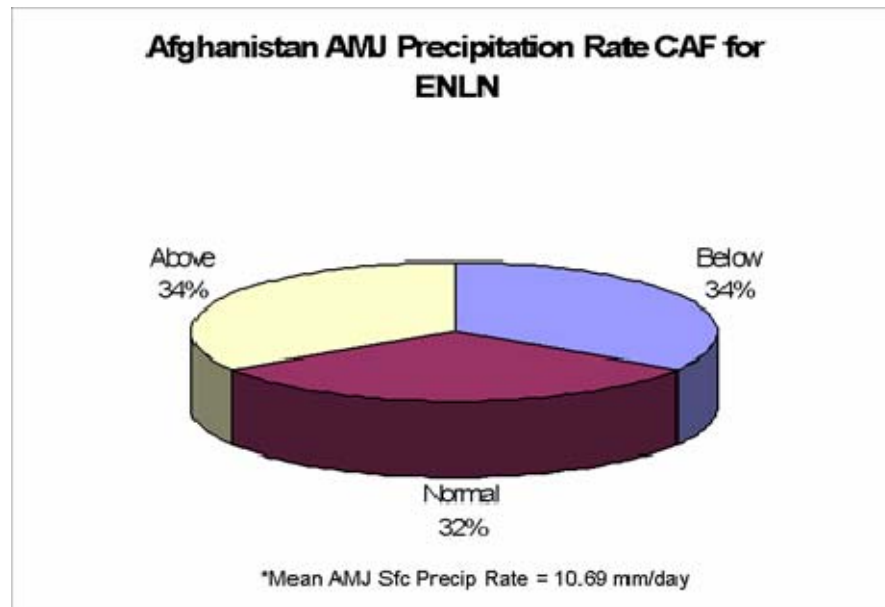


Figure 30. Probabilistic forecast for PRs in AMJ during ENLN. Here, the CAF method is applied using the CPC Niño 3.4 Probabilistic Forecast for AMJ (see Fig. 21). Based on this forecast, there is an equal chance for AN and BN PRs in AMJ 2007.

In the 850hPa temperature distribution, there is an opposite response in the EN distribution of AN and BN 850hPa temperature events when compared to the PR distribution. Here, BN 850hPa temperatures were observed more than AN events, and also as often as NN 850hPa temperatures (44.4%); this also implies that anomalously high precipitation is coupled with anomalously low 850hPa temperatures, instead of anomalously warm 850hPa temperatures, as suggested by Vorhees (2006). This pattern is not as clear as the pattern during OND, where BN and NN 850hPa temperatures were not equally observed over the period of record; however, both seasons are contradictory to the precipitation

and temperature relationships suggested in this previous study. AN 850hPa temperatures were observed most often during the neutral ENLN phase (40%). The fact that NN temperatures did not as often as AN and BN temperatures during this phase indicates that there may be other influences on 850hPa temperatures in AMJ during ENLN.

There was no statistical significance established for AMJ ENLN 850hPa temperatures. The historical composite analysis is still useful for forecasters and commanders, as it identifies conditions observed most (least) often during particular ENLN phases (e.g., heat waves are observed least often during EN events); however, no clear relationship between the climate variation and the distribution of 850hPa temperature events can be established. Further dynamical analysis is required to identify the patterns and processes that are responsible for the distribution of temperatures over Afghanistan. Because no statistical significance was identified for this distribution, the LTM forecasting method was applied. We calculated the mean 850hPa temperature for AMJ to be 20.64°C; in the LTM forecasting method, forecasters would use this information to guide their forecasts and climate inputs to commanders.

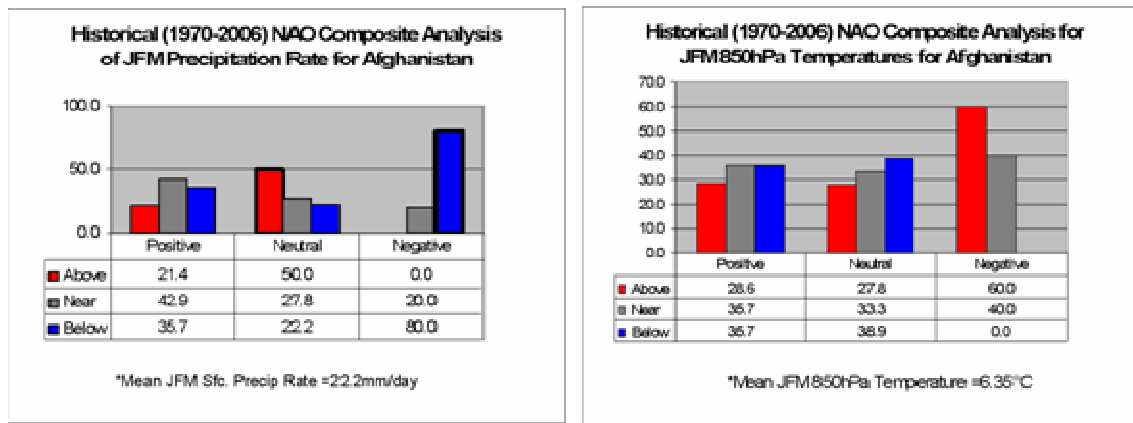


Figure 31. Relative frequency distribution for Afghanistan PR and 850hPa temperature events for JFM observed during NAO phases. We identified 97% statistical significance for AN PR during neutral NAO, and 95.8% statistical significance for BN PR during negative NAO. We applied the CAF method for this scenario (Fig. 34). We could not identify statistical significance for any 850hPa temperature event category for JFM during the NAO. We applied the LTM forecasting method for this scenario.

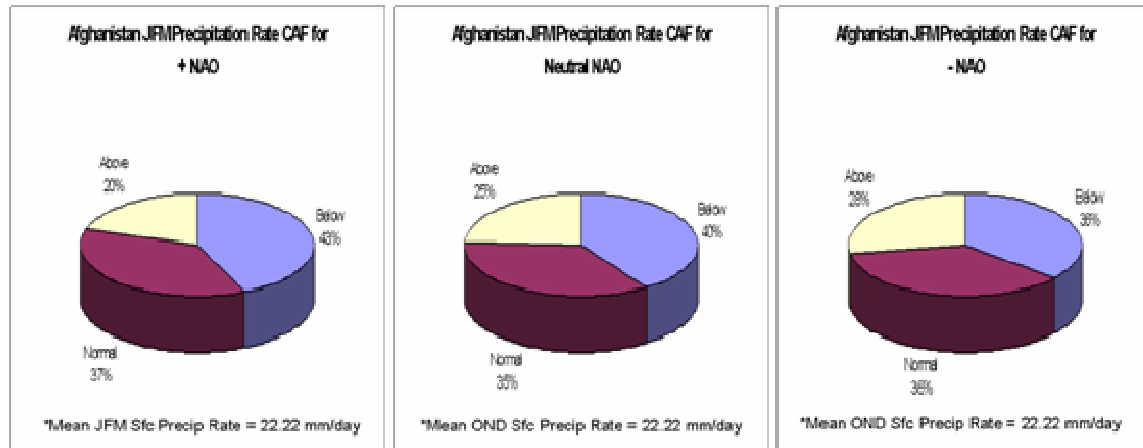


Figure 32. Probabilistic JFM forecast for PR during NAO. The CAF method is applied using TOF probabilities. Based on this forecast, BN PRs are forecasted to occur during +/-neutral NAO (43% and 40%); and there is an equal chance of BN and NN PRs during a negative NAO (36%).

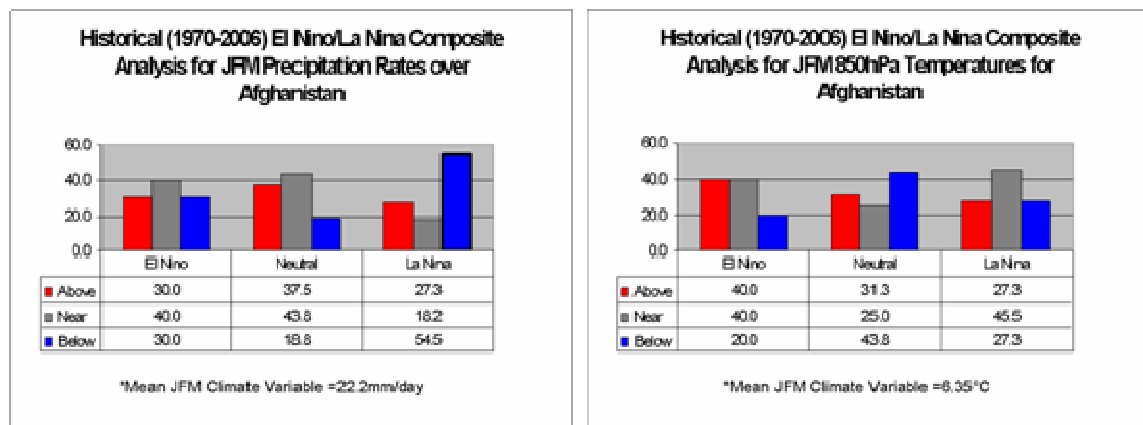


Figure 33. Relative frequency distribution for Afghanistan PR and 850hPa temperature events for JFM observed during ENLN phases. We identified 93% statistical significance for BN PR during LN. We applied the CAF method for this scenario (Fig. 36). We could not identify statistical significance for any 850hPa temperature event category for JFM during the ENLN. We applied the LTM forecasting method for this scenario.



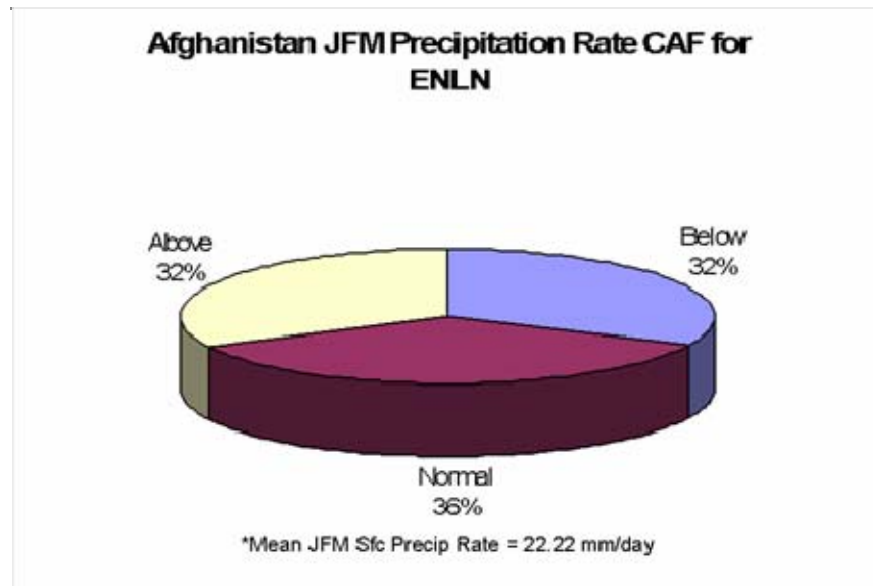


Figure 34. Probabilistic forecast for PRs in JFM during ENLN. Here, the CAF method is applied using the CPC Niño 3.4 Probabilistic Forecast (see Fig. 21). Based on this forecast, NN PRs are forecasted for JFM 2007.

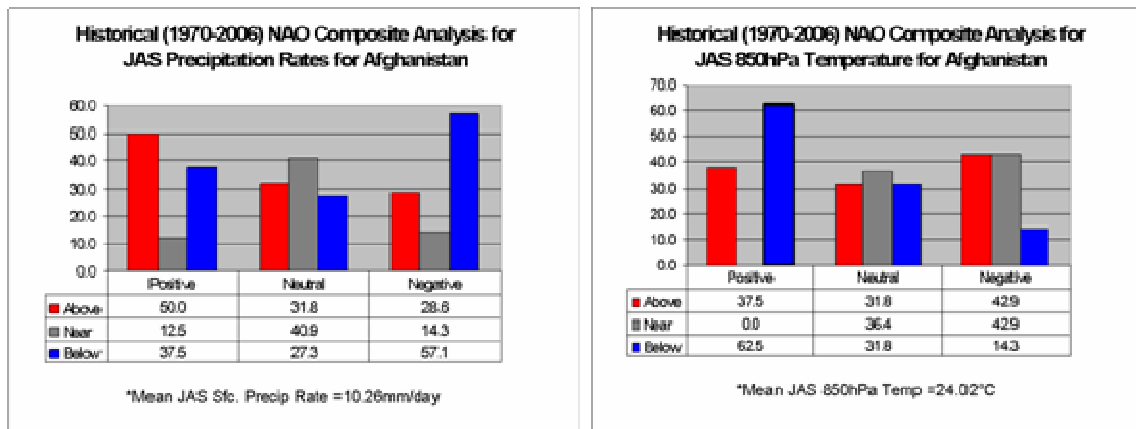


Figure 35. Relative frequency distribution for Afghanistan PR and 850hPa temperature events for JAS observed during NAO phases. We could not identify statistical significance for any JAS PR event category during the NAO. We applied the LTM forecasting method for this scenario. We identified 92% statistical significance for BN 850hPa temperatures during positive NAO. We applied the CAF method for this scenario (Fig. 38).

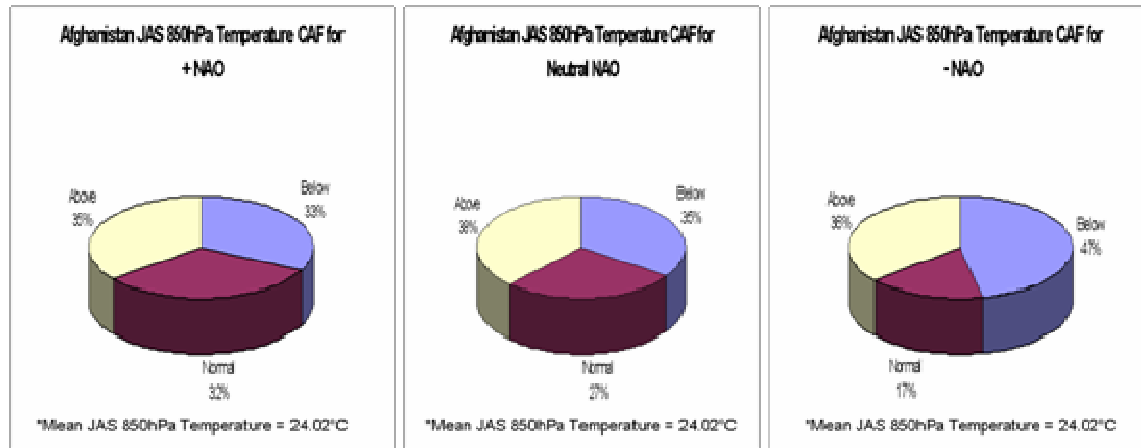


Figure 36. Probabilistic JAS forecast for 850hPa temperatures during the NAO. The CAF method is applied using TOF probabilities. Based on this forecast, AN 850hPa temperatures are forecasted to occur during +/-neutral NAO (35% and 38%), and BN 850hPa temperatures are forecasted to occur during a negative NAO (47%).

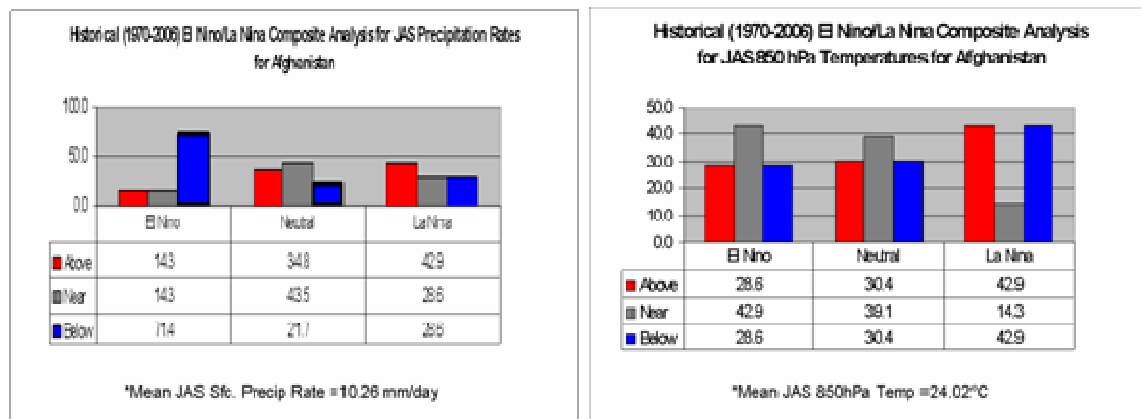


Figure 37. Relative frequency distribution for Afghanistan PR and 850hPa temperature events for JAS observed during ENLN phases. We identified 97.5% statistical significance for BN PR during EN, and 92.1% statistical significance for BN PR during neutral ENLN. We applied the CAF method for this scenario (Fig. 40). We could not identify statistical significance for any 850hPa temperature event category during the ENLN. We applied the LTM forecasting method for this scenario.

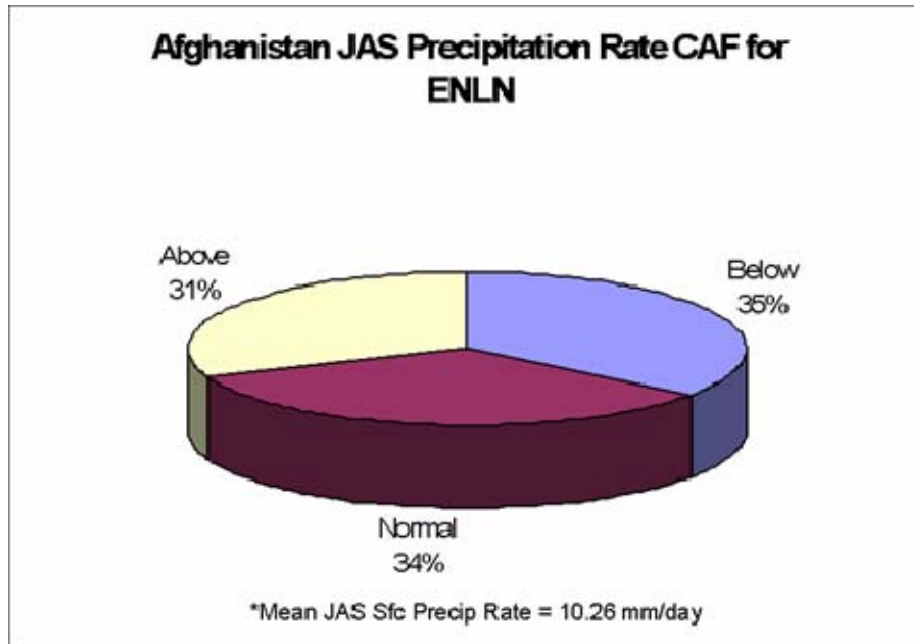


Figure 38. Probabilistic forecast for PRs in JAS during ENLN. Here, the CAF method is applied using the CPC Niño 3.4 Probabilistic Forecast (see Fig. 21). Based on this forecast, BN PRs are forecasted to occur in JAS 2007.

#### E. AFGHANISTAN AUTUMN 2004 CASE STUDY

To demonstrate the usefulness of a composite analysis and the CAF process, we performed a composite analysis of PR and 850hPa temperatures based on data from January 1970 through summer 2004. In other words, we withheld data from autumn 2005 onward so that we could simulate the situation that forecasters would have faced when forecasting for autumn 2004. This allowed us to conduct a realistic test of the CAF process for an autumn in which large anomalies were observed (see Chapter I discussion of the winter of 2004-2005). Doing so allowed us to determine if our methods would have provided forecasters and commanders with information that may have foreshadowed the events that took place in Afghanistan in autumn (OND) 2004 through winter (JFM) 2005.

Figures 39 and 40 compare the OND composite analysis results derived from using the two different data periods (1970-2006 and 1970-2004). Figure 39 shows that the relative frequency distributions for NAO were very similar between

the two data periods. The major differences are in the SS results, with no SS results for PR when using the shorter data period.

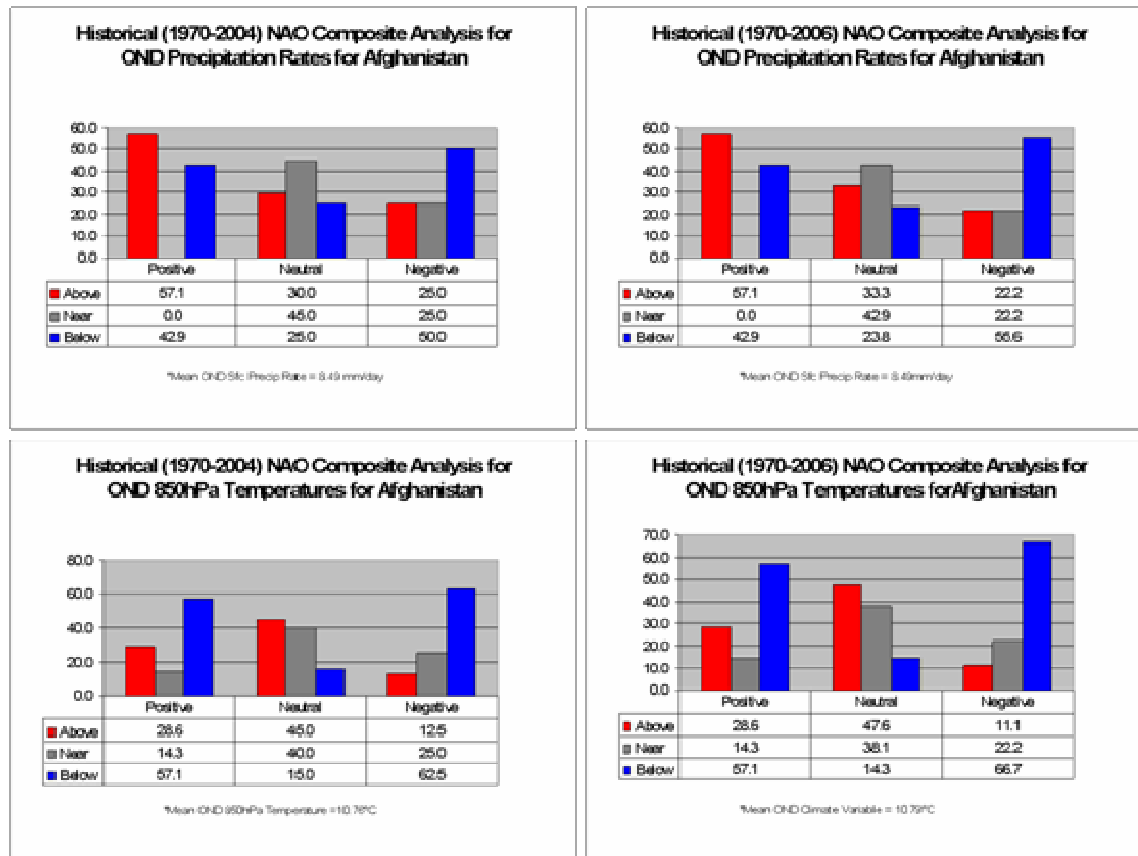


Figure 39. Comparison of OND NAO PR and 850hPa temperature composite analyses performed for Afghanistan from 1970-2004 (left panels) and 1970-2006 (right panels).

For the shorter data period, there were SS results for 850hPa temperature, although fewer than for the longer data period. The SS results were: 93% statistical significance for BN temperatures during neutral NAO and 99.2% statistical significance for BN temperatures during positive NAO. The major difference between the two scenarios is that there is no statistical significance associated with the negative phase of the NAO during 1970-2004. It is important to note, however, that strong statistical significance is associated with BN temperatures during a positive NAO in both scenarios. Increasing the number of events had no real influence on this phase category and thus, we can

conclude that forecasters would have been able to use a historical composite analysis to provide commanders with actionable climate information for autumn 2004.

Fig. 39 shows that the composite analysis and SS results for PR and 850hPa temperature were very similar for the two data periods. Thus, forecasters would have been able to use ENLN forecasts to issue a CAF for Afghanistan for OND 2004. These forecasts would have been an improvement on forecasts based on LTMs, the standard for DoD forecasters then and now.

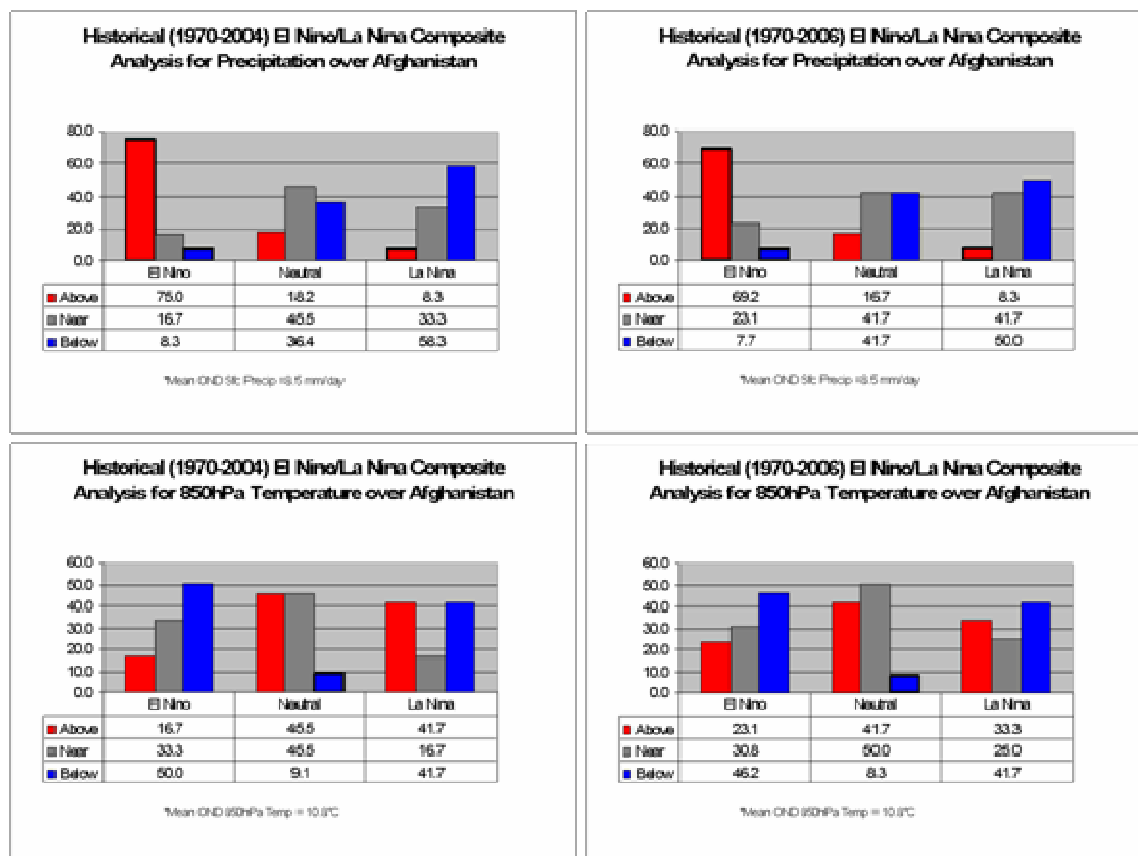


Figure 40. Comparison of OND ENLN PR and 850hPa temperature composite analyses performed for Afghanistan from 1970-2004 (left panels) and 1970-2006 (right panels).

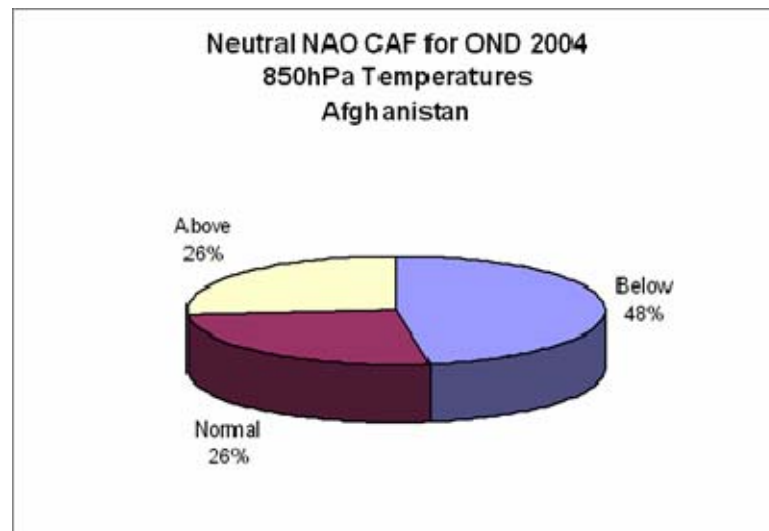
The Niño 3.4 index was positive in late spring 2004 and became more positive through fall 2004, consistent with the development of EN conditions in the tropical Pacific. Knowing that an EN event was building during the summer 2004, and knowing that composite analyses show that autumn precipitation tends

to be anomalously high in Afghanistan during EN, forecasters would have likely informed commanders, at lead times of several weeks or more, that the 2004 autumn would have higher precipitation than normal. In addition, knowing that composite analyses show that autumn temperatures in Afghanistan tend to be cooler than normal during EN, forecasters would have likely predicted a higher probability of anomalously low temperatures during OND 2004. During OND 2004, precipitation was anomalously high and 850hPa temperatures were normal or above normal (not shown). Thus, forecasts based on the composite analysis results alone would have verified for precipitation but not for 850hPa temperature.

However, the complete simulated forecasts for OND 2004 involves going beyond the composite analyses (Figs. 39-40) to generate CAFs based on forecasts of the ENLN and NAO phases. We were unable to generate CAFs based on ENLN, since the Niño 3.4 index forecasts were not available past 2002. The NAO index value for JAS 2004 was 0.343; this classifies the NAO phase as neutral. Therefore, we applied the CAF method based on the TOF for a neutral phase in JAS (see the middle of the lower left panel in Fig. 19). This gave us a forecast of 850hPa temperatures for OND 2004 which gave a 48% probability of BN 850hPa temperatures (Fig. 41). The mean OND 850hPa temperature is 10.76°C, and the threshold for BN 850hPa temperatures is 10.56°C. The observed 850hPa temperature for OND 2004 (using the NCEP/NCAR reanalysis data) was 10.97°C, indicating NN temperature conditions. Had the forecast solely forecasted BN temperatures, it would not have verified; however, because there was still a probability (26%) for NN temperatures, this forecast is still accurate. Also, given the results in Figure 40 and the evolution of the EN conditions during summer 2004, it seems likely that a CAF based on an ENLN forecast would have also provided useful and accurate information for forecasters.

This case study illustrates one of the challenges that forecasters need to resolve when CAFs are available for one predictand (e.g., Afghanistan PR in OND) but based on two or more predictors (e.g., ENLN and NAO phase in OND). In this case, forecasters need to be able to choose which of the two CAFs is

more likely to verify. Ideally, multi-predictor CAFs would be available to, in effect, merge the forecasts based on two or more predictors. The difficulty with multi-predictor CAFs is that the number of predictor categories for the composite analyses goes up which causes the sample size to go down, which reduces the number of SS results. This issue is discussed further in Chapter IV.



-JAS NAO Index: 0.343

- Mean OND 850hPa Temperature = 10.76°C

- Observed OND 2004 850hPa Temperature = 10.97°C

Figure 41. CAF based on NAO for OND 2004. The NAO Index value for JAS 2004 was 0.343, corresponding to the neutral NAO phase. The neutral NAO phase CAF for 850hPa temperatures for OND 2004 forecasts 48% chance of BN temperatures and equal chances (26%) for AN and NN temperatures.

## F. SUMMARY OF RESULTS

The results presented here clearly demonstrate that large-scale climate variations (e.g., ENLN and NAO) must be considered when forecasting for Afghanistan. Originating in almost opposite regions of the world, our study showed that both tropical (ENLN) and extratropical (NAO) climate variations have statistically significant impacts on 850hPa temperatures and PRs in the region, and that these impacts can vary from season to season.

The OND season had the largest number of statistically significant results from each climate variation, with five statistically significant NAO results and four

statistically significant ENLN results. The AMJ season had the second largest number for both climate variations, each with three statistically significant results. The JFM and JAS seasons each had three total statistically significant results. When we considered the two climate variations separately, we found that the NAO had 11 statistically significant results across all four seasons, while ENLN had ten statistically significant results across all four seasons. NAO had more statistically significant results for 850hPa temperatures, and ENLN had more statistically significant results for PRs. The distinction between the impacts from each climate variation may be attributed to the mechanisms by which they affect Afghanistan.

ENLN is a tropical climate variation, originating in the equatorial tropical Pacific Ocean. During OND and JFM of EN events, there is tends to be a pronounced decrease in convection over the MC region and the corresponding development of an anomalous lower tropospheric anticyclonic circulation over India that advects moisture into SWA and provides extra fuel for the ETCs transiting Afghanistan in the fall and winter (Vorhees 2006). The reverse occurs during LN events. Afghanistan is relatively close to the IO moisture source for the anomalous circulations over India, which may help explain why ENLN is linked mainly to anomalous precipitation in Afghanistan during OND and JFM.

The NAO is an extratropical climate variation, originating in the North Atlantic Ocean. Vorhees (2006) found that when there is a positively phased NAO, there is an increase in northerly winds into SWA, advecting colder, drier air into the region. Conversely, when there is a negatively phased NAO, there is an increase in moisture advection from the eastern Mediterranean Sea into SWA. Afghanistan is a considerable distance from this moisture source, and there is significant topography between Afghanistan and the Mediterranean, This may help explain why the NAO is mainly linked to anomalous 850hPa temperatures in OND and JFM.

The statistically significant results uncovered in this study are summarized in Tables 2-5.



## NAO Composite Analysis Summary for Afghanistan

Relative Frequency Distribution of Afghanistan Seasonal Precipitation Events					
Phase	Category	JFM	AMJ	JAS	OND
<b>+ NAO</b>	<b>AN</b>	21.4	<u><b>80.0</b></u>	50.0	57.1
	<b>NN</b>	50.0	0.0	12.5	0.0
	<b>BN</b>	0.0	20.0	37.5	42.9
<b>Neutral</b>	<b>AN</b>	<u><b>42.9</b></u>	25.1	31.8	33.3
	<b>NN</b>	27.8	34.6	40.9	42.9
	<b>BN</b>	20.0	42.3	27.3	<u><b>23.8</b></u>
<b>-NAO</b>	<b>AN</b>	35.7	50.0	28.6	22.2
	<b>NN</b>	22.2	33.3	14.3	22.2
	<b>BN</b>	<u><b>80.0</b></u>	16.7	57.1	55.6
Forecast Method to Apply		<b>CAF</b>	<b>CAF</b>	<b>LTM</b>	<b>CAF</b>

**Note:** Underlined values are those with a Statistical Significance  $\geq 0.90$

Table 2. Composite analysis summary for NAO PRs for Afghanistan. SS results, shown in bold and underlined, were identified for JFM, AMJ, and OND. Thus, the CAF method was applied to these three seasons.

## NAO Composite Analysis Summary for Afghanistan

Relative Frequency Distribution of Afghanistan Seasonal 850hPa Temperature Events					
Phase	Category	JFM	AMJ	JAS	OND
<b>+ NAO</b>	<b>AN</b>	28.6	20	37.5	28.6
	<b>NN</b>	35.7	20	0	14.3
	<b>BN</b>	35.7	60	<u>62.5</u>	57.1
<b>Neutral</b>	<b>AN</b>	27.6	45.2	31.8	<u>47.6</u>
	<b>NN</b>	33.3	30.8	36.4	38.1
	<b>BN</b>	36.9	23.1	31.8	<u>14.3</u>
<b>-NAO</b>	<b>AN</b>	60	0	42.9	<u>11.1</u>
	<b>NN</b>	40	33.3	42.9	27.2
	<b>BN</b>	0	<u>66.7</u>	14.3	<u>66.7</u>
Forecast Method to Apply		LTM	CAF	CAF	CAF

**Note:** Underlined values are those with a Statistical Significance  $\geq 0.90$

Table 3. Composite Analysis summary for 850hPa temperatures during NAO for Afghanistan. Statistical significance was identified in AMJ, JAS, and OND and therefore, the CAF method was applied in three out of four seasons.

## ENLN Composite Analysis Summary for Afghanistan

<b>Relative Frequency Distribution of Afghanistan Seasonal Precipitation Events</b>					
<b>Phase</b>	<b>Category</b>	<b>JFM</b>	<b>AMJ</b>	<b>JAS</b>	<b>OND</b>
<b>EN</b>	<b>AN</b>	30.0	<u>77.8</u>	14.3	69.2
	<b>NN</b>	40.0	11.1	14.3	23.1
	<b>BN</b>	40.0	11.1	<u>71.4</u>	<u>7.7</u>
<b>Neutral</b>	<b>AN</b>	37.5	25	34.8	16.7
	<b>NN</b>	43.8	45	43.5	41.7
	<b>BN</b>	16.6	30	<u>21.7</u>	41.7
<b>LN</b>	<b>AN</b>	27.3	<u>0</u>	42.9	<u>8.3</u>
	<b>NN</b>	18.2	37.5	28.6	41.7
	<b>BN</b>	<u>54.2</u>	<u>62.5</u>	28.6	50
<b>Forecast Method to Apply</b>		<b>CAF</b>	<b>CAF</b>	<b>CAF</b>	<b>CAF</b>

**Note:** Underlined values are those with a Statistical Significance  $\geq 0.90$

Table 4. Composite Analysis summary for PRs during ENLN for Afghanistan. Statistical significance was identified in all four seasons and therefore, the CAF method was for each.

## **ENLN Composite Analysis Summary for Afghanistan**

<b>Relative Frequency Distribution of Afghanistan Seasonal 850hPa Temperature Events</b>					
<b>Phase</b>	<b>Category</b>	<b>JFM</b>	<b>AMJ</b>	<b>JAS</b>	<b>OND</b>
<b>EN</b>	<b>AN</b>	40	11.1	28.6	23.1
	<b>NN</b>	40	44.4	42.9	30.8
	<b>BN</b>	20	44.4	28.6	46.2
<b>Neutral</b>	<b>AN</b>	31.3	40	30.4	41.7
	<b>NN</b>	25	35	39.1	50
	<b>BN</b>	43.6	25	30.4	<u>8.3</u>
<b>LN</b>	<b>AN</b>	27.3	37.5	42.9	33.3
	<b>NN</b>	45.5	25	14.3	25
	<b>BN</b>	27.3	37.5	42.9	41.7
<b>Forecast Method to Apply</b>		<b>LTM</b>	<b>LTM</b>	<b>LTM</b>	<b>CAF</b>

**Note:** Underlined values are those with a Statistical Significance  $\geq 0.90$

Table 5. Composite Analysis summary for 850hPa temperatures during ENLN for Afghanistan. Statistical significance was identified only in OND and therefore, the LTM forecasting method was applied in three out of four seasons.

## **IV. SUMMARY AND CONCLUSIONS**

### **A. SUMMARY**

This study investigated the impacts of ENLN and NAO on Afghanistan. In addition to assigning statistical significance to the relationships previously established between ENLN and SWA by Barlow et al. (2005) and Vorhees (2006), we have also identified statistically significant NAO results in Afghanistan. Previous studies on the impacts in Afghanistan from the NAO were inconclusive; this study shows that the impacts of NAO on Afghanistan may be as important as those of ENLN.

We used the NCEP/NCAR reanalysis data and the Niño 3.4 and NAO indices to examine impacts on 850hPa temperatures and surface precipitation rates in Afghanistan during all seasons. Using the composite analysis method developed and used by NOAA, we were able to identify statistically significant results for each climate variation and each predictand. In addition to corroborating many of the relationships identified in previous studies, we found some relationships that contradict those from prior studies. For example, Vorhees (2006) found that for SWA as a whole, anomalously high precipitation tends to occur with anomalously high temperatures. Our study found the opposite to be true for Afghanistan, where anomalously high precipitation tends to occur simultaneously with anomalously low temperatures.

### **B. STATISTICALLY SIGNIFICANT COMPOSITE ANALYSIS RESULTS**

#### **1. JFM**

For this season, there were no statistically significant ENLN 850hPa temperature results and one statistically significant ENLN PR result. There were no statistically significant NAO 850hPa temperatures results and two statistically significant NAO PR results.

## **2. AMJ**

There were no statistically significant ENLN 850hPa temperature results and three statistically significant ENLN PR results. There were two statistically significant NAO 850hPa temperature results and one statistically significant NAO PR result.

## **3. JAS**

There were no statistically significant ENLN 850hPa temperature results and two statistically significant ENLN PR results. There was one statistically significant NAO 850hPa temperature results and no statistically significant NAO PR results.

## **4. OND**

There was one statistically significant ENLN 850hPa temperature result and three statistically significant ENLN PR results. There were four statistically significant NAO 850hPa temperature results and one statistically significant NAO PR results.

## **5. Composite Analysis Forecasts**

We identified a total of eleven statistically significant NAO results over both predictands in all four seasons, and ten statistically significant ENLN results over both variables in all four seasons. For these statistically significant seasons and variables, we applied the CAF method to generate a probabilistic forecast, resulting in five ENLN CAFs and six NAO CAFs. For those seasons and variables where there were no statistically significant results, we applied the LTM forecasting method; there were three ENLN composited seasons and two NAO composited seasons for which the LTM was the basis for the forecast.

## **C. APPLICATIONS TO DOD OPERATIONS**

Our methods are an example of modern, or smart, climatology and are modeled after methods currently used by the civilian climate community. We adapted these methods to a region of interest to the DoD and demonstrated that forecasts based on ENLN and NAO would be an improvement on forecasts based on LTMs. Forecasts based on LTMs are, in effect, the forecasts presently available from DoD climatology centers, such as AFCCC. Our case study of

autumn 2004 indicated that had these methods been used by military forecasters and commanders, the anomalous precipitation that led to catastrophic events during autumn 2004 and winter 2005 could have been accounted for.

Adapting methods such as the composite analysis used in this study will begin to bridge the gap between the military and civilian climate communities. Our study has shown that these methods are viable and effective in the data sparse regions that are of continued political interest to the DoD. Foreseeing events similar to those that impacted Afghanistan in fall 2004 and winter 2005 will mitigate personnel losses and equipment damages and protect resources.

#### **D. RECOMMENDATIONS FOR FUTURE RESEARCH**

As this area of research continues to draw interest from all corners of the climate community, there are many questions still to be answered.

##### **1. Trend Adjustment**

Our study did not account for long term trends in the predictors (Figs. 16-17). Incorporating trend adjustments into the composite analysis methods would provide a more up-to-date, accurate historical composite analysis of a variable during a particular phase of a climate variation. Based on the results in Figure 16, we recommend applying a the global warming trend adjustment. These results indicate decadal scale trends (e.g., warming since about 1970) that should be accounted for in future applications of our methodology.

##### **2. Verification of CAF**

Our study has shown that an existing methodology is effective in more data sparse regions such as Afghanistan; however, it does not show how well the method works. A complete investigation into verifying the method must be done that includes verification of the resulting forecasts. We recommend calculating a Heidke Skill Score, total and individual event (AN, NN, and BN) probabilities of detection, and total and individual event (AN, NN, and BN) false alarm rates for each forecasted variable event probability in each season, and for each climate

variation. A 3 x 3 contingency table and the methods highlighted by Wilks (2006) form a good starting point for verifying CAFs for any region, climate variation, and data set.

### **3. Regional Product**

There is potential for extending the application of the CAF method to a larger spatial scale. One example is a regional (e.g., SWA vs. Afghanistan) product, where composite analysis is performed for several locations across the region (e.g., Baghdad, IQ, Tehran, IR, and Kabul, AF) and a regional consensus is reached on the CAF for the entire area. This type of product currently exists in the civilian sector in products issued by CPC and IRI (see Ch. 1, section D). This same concept can be applied in a DoD sense by performing the same composite analysis methods to develop large-scale products on a major command (MAJCOM) level. The product would graphically display a consensus CAF for each individual MAJCOM as opposed to a specific geographical region.

### **4. Cost Analysis**

On the surface, the cost required to implement composite analysis in operational military weather seems relatively low. At a bare minimum, forecast centers would require access to the NCEP/NCAR reanalysis data and Excel software. To be certain of all requirements, however, we recommend an in-depth cost analysis study to provide the specific requirements for implementation and maintenance of the application. This study should highlight the financial benefits to the DoD, as well as the overall fiscal cost from year to year. Training requirements must also be accounted for. We feel that forecasters would require two days of in-class instruction to learn the procedure and then three days of application in a training environment; one total week of in-residence instruction would be sufficient to integrate the composite analysis method into DoD forecast centers.

### **5. Military Forecasting Prototype**

We provided CAFs for each statistically significant variable identified in by our methods. The pie-chart representation is one method of conveying these forecasts, but the possibilities are numerous. It is possible to alter the concept for



extended use in the operational military arena by using operational thresholds as tercile values instead of the calculated tercile values in the data set. For example, instead of using the upper and lower limit 850hPa temperature values from our data set, we could input the operational thresholds for personnel; for example, determine the relative frequency distribution of personnel impacts, and provide a probabilistic forecast of operational thresholds for a region during each phase of a climate variation. This information could provide commanders with long range, specific windows of opportunity to plan for and position assets necessary to conduct specific missions in a particular region.

## **6. Other Applications of Composite Analysis**

The methods used in this study could be applied in different ways that would also provide useful results. These different ways include:

a. Apply different timescales. Investigating climate variation impacts over shorter or longer averaging times (e.g., two weeks to one month) may provide more substantial or identifiable results.

b. Use other data sets. The NCEP/NCAR reanalysis data provided us with the most complete period of record for our study; however, there are other options to consider, especially if shorter periods of record are used. The ACMES data set maintained by AFCCC provides spatially higher resolution data, but for a shorter periods (e.g., ten years). Surface observations are incomplete for many locations in SWA, but may be complete enough for other timescale applications of our methods.

c. Investigate additional predictands. We chose to investigate 850hPa temperatures and PRs because of their application to a large number of operational missions, but there are other variables to consider. Examples include surface winds and cloud cover.

d. Investigate climate impacts on other regions. Now that our method has established the feasibility of composite analysis in data sparse regions, other regions should be considered, such as Africa, Southeast Asia, South America.

e. Vary the climate index phase thresholds. We used  $\pm 0.5$  for Niño 3.4 and the NAO Index. Using higher or lower phase threshold values may provide different insights into the regional climate impacts.

f. Investigate other large-scale climate variations. We chose ENLN and the NAO because of the many studies that have linked them to the SWA region. But other climate variations are also linked to the SWA region, including the Indian Ocean Zonal Mode (IOZM) and the Madden-Julian Oscillation (MJO). Performing correlation and composite analyses would provide a very in-depth look into the impacts on the SWA climate system.

## **7. Dynamical Correlation Analysis**

Our study did not attempt to identify the dynamic patterns and processes that may be responsible for our results. In-depth correlation analyses are one way to uncover these patterns and processes. We recommend employing both forward and backward approaches to the correlation analysis. Specifically, there should be correlations of climate variation indices with variables in the region of interest (e.g., correlation of Niño 3.4 with 850hPa temperatures in the region of interest). These are sometimes referred to as forward teleconnection analyses, since they work forward in a dynamical sense from the presumed global cause to the presumed regional effects. There should also be reverse, or backward, teleconnections analyses, in which regional variables are correlated with global fields (e.g., precipitation in the region of interest correlated with winds everywhere else). These correlations will aid in identifying global, regional, and perhaps local patterns and processes that would explain climate anomalies for a particular area.

For the military planner and operator, weather is often an obstacle to be overcome or avoided. Smart climatological techniques offer the DoD the opportunity to exploit the weather in the battle space weeks or months ahead of operations. This study is only one step further towards incorporating more modern, or smart, climatological methods into DoD weather, and there is a long road ahead before operational military products are up to par with those of the civilian climate community. There is great potential for future research on this

topic, and it is research that must be completed in order to bridge the gap. We hope this study serves as one large step in the right direction.

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